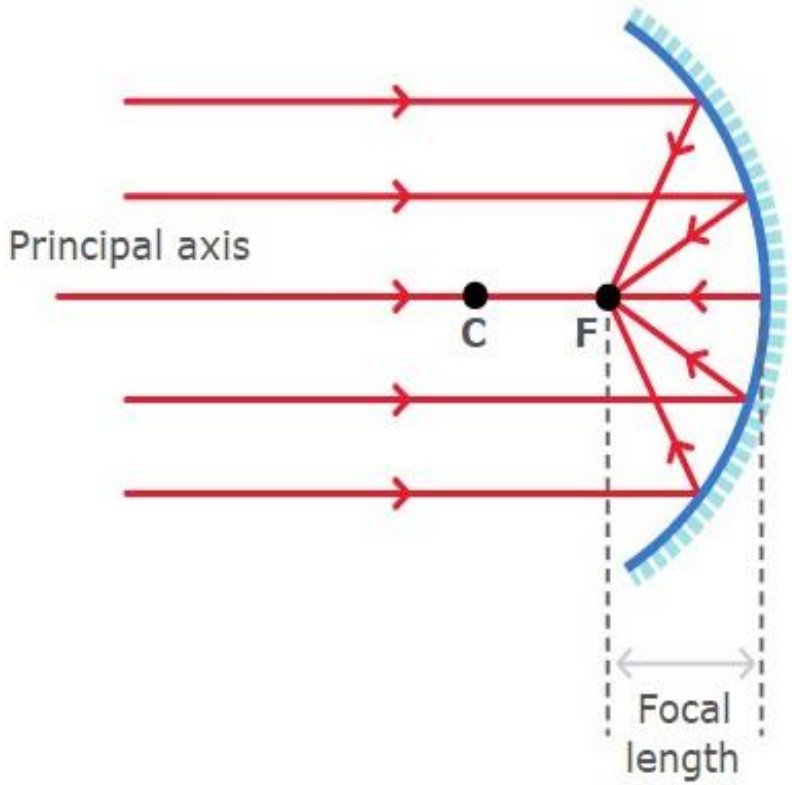
New Capital College

Class 11-Physics
Optics

Reflection of light on a concave mirror



Reflection of light on convex mirror

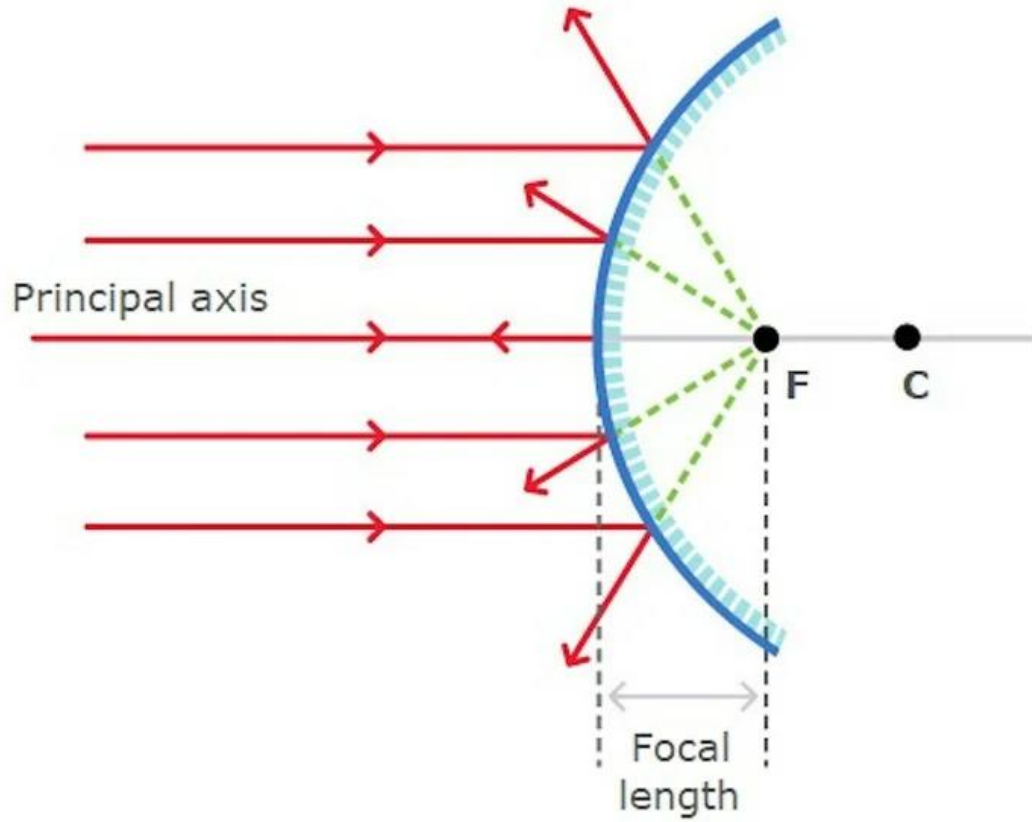


Image Formation: Image are formed when light rays from an object are redirected , either by reflection or refraction and converge at a point or appear to converge , to create a representation of that object. There are two types of image . They are

a) Real Image: It is formed by the actual intersection of reflected or refracted rays. It can be obtained on the screen. It is inverted with respect to the object. Examples: Image projected onto a cinema screen, camera sensor, retina of the eye etc.
b) Virtual Image: It is formed by the virtual intersection of reflected or refracted rays. It can't be obtained on the screen. It is erected with respect to the object. Examples: Magnifying glass, flat mirror reflection etc.

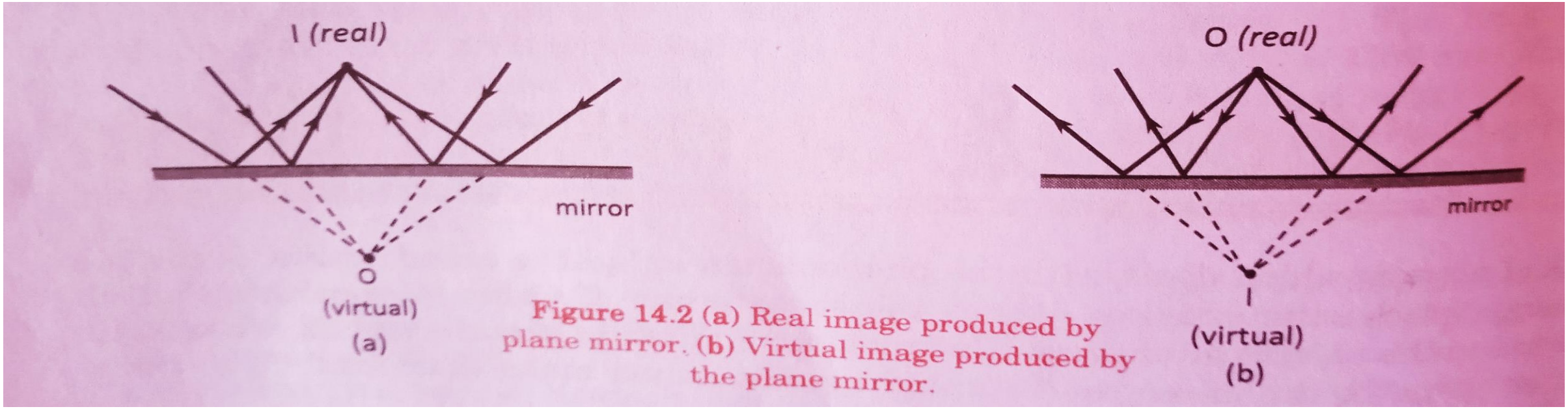


Figure 14.2 (a) Real image produced by plane mirror. (b) Virtual image produced by the plane mirror.

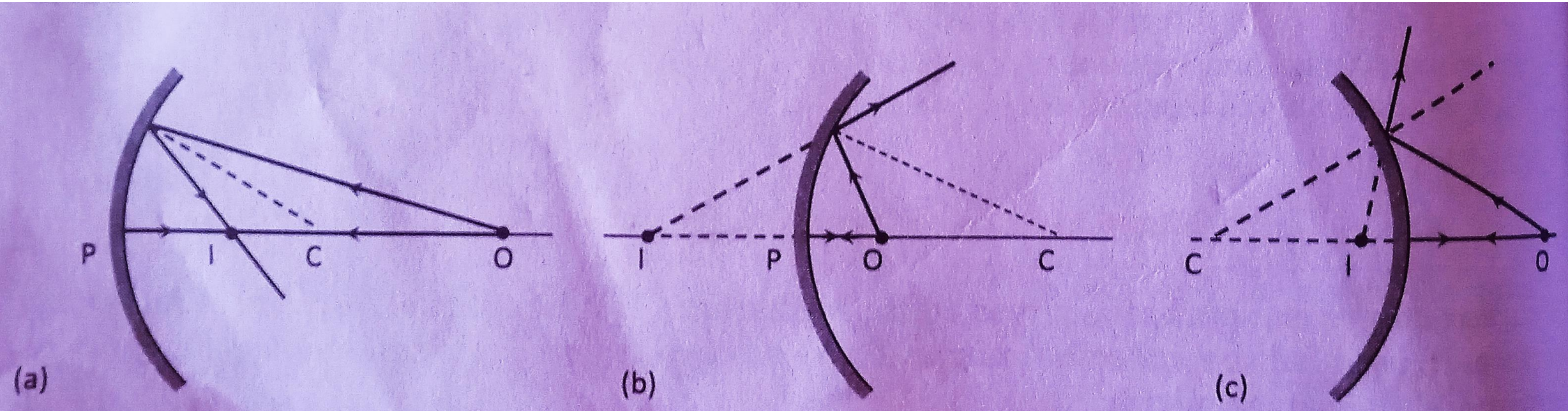
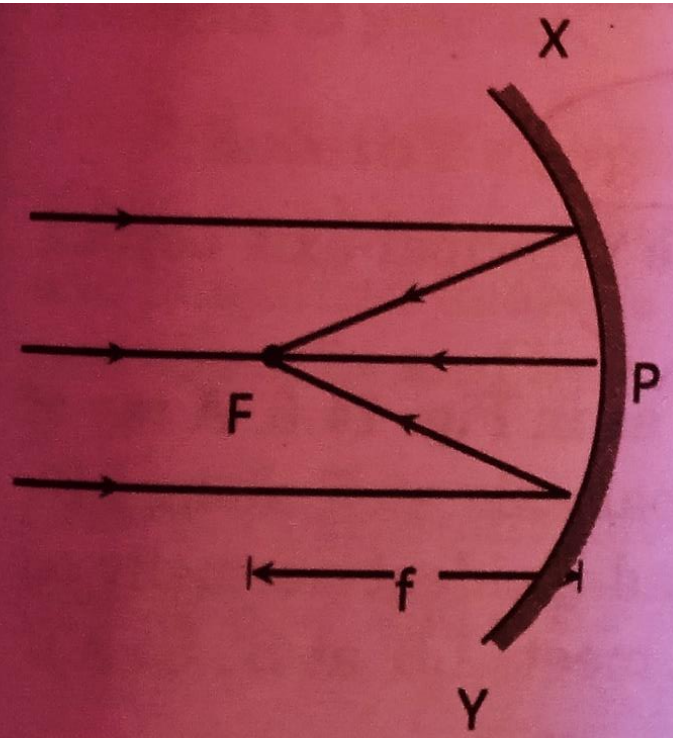


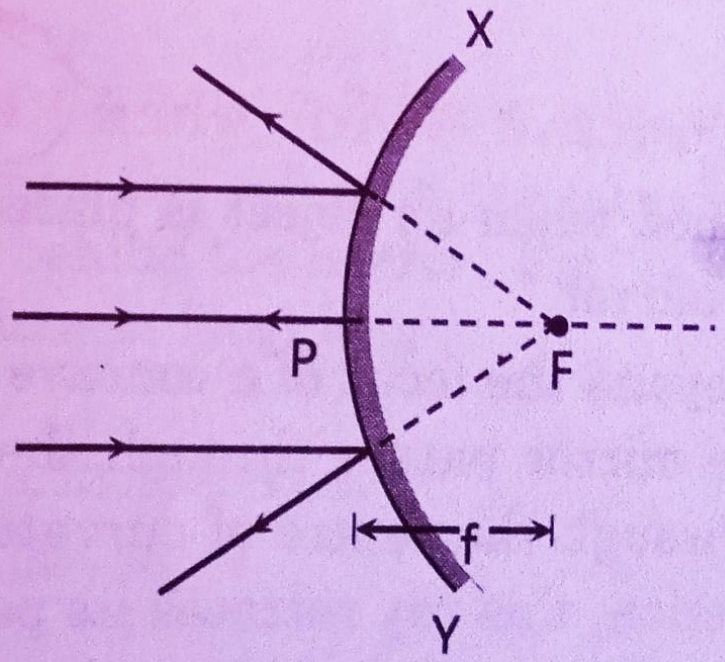
Figure 14.3 (a) A real image I formed by concave mirror. (b) A virtual image I formed by concave mirror. (c) A virtual image I formed by convex mirror.

Important terms used in spherical mirror:

a) **Aperture:** The effective width of a spherical mirror from which reflection can take place is called aperture.
b) **Pole:** The center of the spherical reflecting surface of the mirror is called pole, (P).
c) **Centre of curvature:** The center of the sphere which is a part of the mirror is called centre of curvature, (C).
d) **Radius of curvature:** The radius of the sphere which is part of the mirror is called radius of curvature. It is denoted by R.
e) **Principal axis:** The line passing through the pole and centre of curvature is called principal axis.
f) **Principal focus:** A point, where all the parallel beam of light after reflection, converges or appears to diverge is called the principal focus, F.
g) **Focal length:** The distance between the pole and principle focus of a mirror is called the focal length, denoted by f.



(a)



(b)

Figure 14.4 (a) A parallel beam is converged at F by concave mirror, (b) A parallel beam diverged by convex mirror appears to come from F.

Relation between Radius of curvature (R) and focal length (f):

Consider a concave mirror of small aperture as shown in figure. When a ray of light OA parallel to the principal axis is incident at point A on the mirror, it will be reflected along AB that passes through the focus F. Join AC which is normal to A.

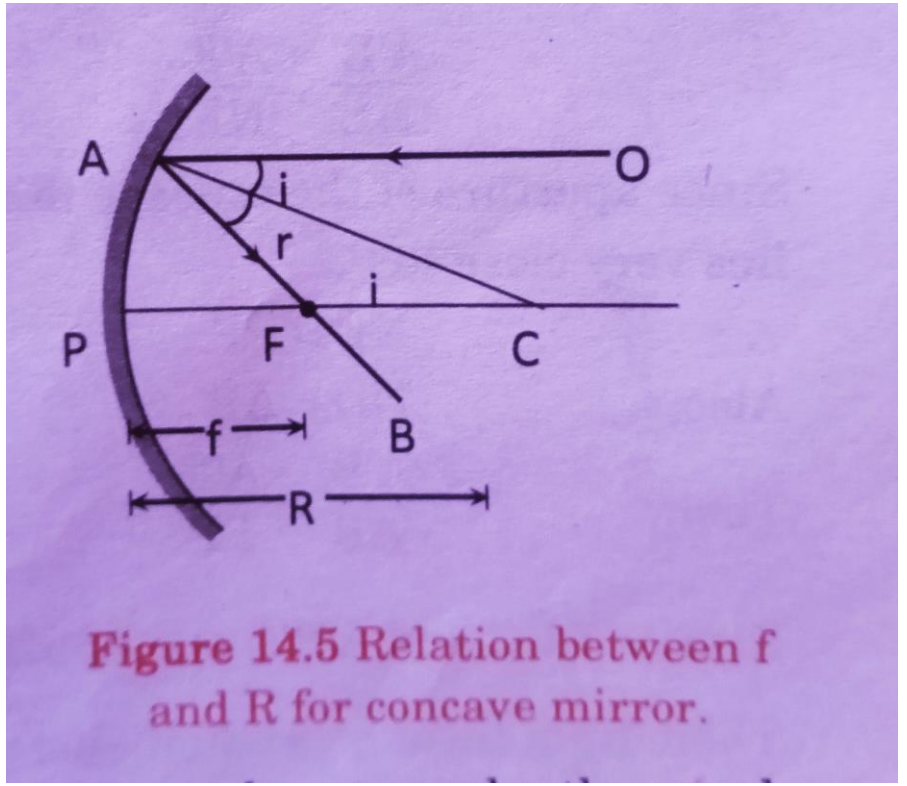


Figure 14.5 Relation between f and R for concave mirror.

From laws of reflection of light,

$\angle OAC = \angle BAC$

And $\angle OAC = \angle ACF$ due to alternate angle.

Therefore, $\angle BAC = \angle ACF$

Hence ΔAFC is an isosceles triangle and in such triangle, AF=FC

If the aperture of the mirror is small, then points A and P are very close to each other, and we will have AF= PF. Then,

$$\Rightarrow PF=FC=PC-PF$$

$$\Rightarrow 2PF=PC$$

$$\Rightarrow 2f=R$$

$\Rightarrow f=R/2$

Where f is focal length and R is radius of curvature of the mirror. Thus, the focal length of a concave mirror is one half of its radius of curvature.

Mirror Formula: An expression showing the relation between object distance, image distance and focal length of a mirror is called the mirror formula.

Mirror formula for concave mirror when real image is formed:

Let an object AB is placed on the principal axis beyond the centre of curvature of a concave mirror of focal length 'f'. Also let A'B' be the real image formed by that mirror. Draw LN perpendicular on the principal axis.

Now Δ's NLF and A'B'F are similar, and therefore

$$\frac{A'B'}{NL} = \frac{A'F}{NF}$$

Since aperture of the concave mirror is small , so the point N lies very close to P.

NF= PF

Also, NL = AB

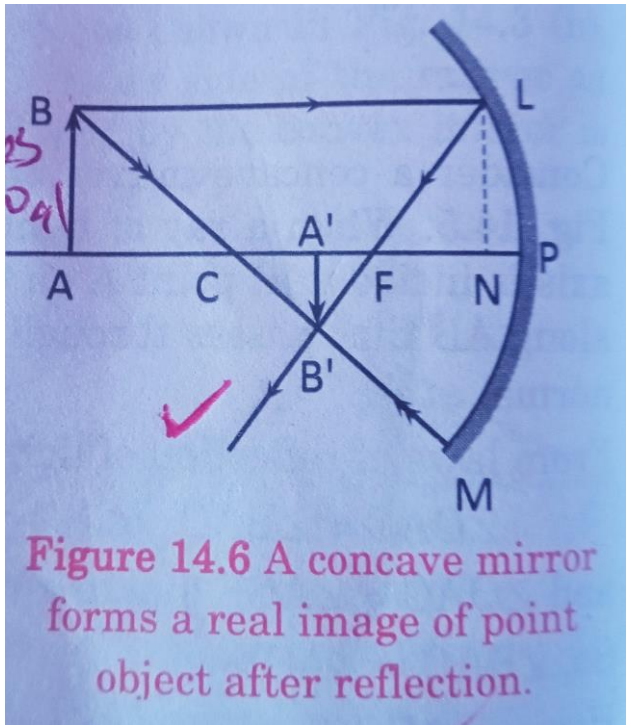


Figure 14.6 A concave mirror forms a real image of point object after reflection.

Then,

$$\frac{A'B'}{AB} = \frac{A'F}{PF}$$

Also Δ's ABC and A'B'C' are similar , therefore

$$\frac{A'B'}{AB} = \frac{A'C}{AC}$$

Then, from these two equations , we get

$$\frac{A'F}{PF} = \frac{A'C}{AC} \quad \text{.....(1)}$$

Since, all the distances are measured from the pole of the mirror , so A'F=PA-PF, A'C=PC-PA' and AC=PA-PC . Thus, above equation becomes

$$\frac{PA'-PF}{PF} = \frac{PC-PA'}{PA-PC} \quad \text{.....(2)}$$

But, PA= u (object distance) , PA'= v (image distance), PF=f, PC =R= 2f

Hence , equation (2) becomes

$$\Rightarrow \frac{v-f}{f} = \frac{2f-v}{u-2f} \quad \text{.....(3)}$$

$$\Rightarrow uv - 2vf - uf + 2f^2 = 2f^2 - vf$$

$$\Rightarrow uv=uf+vf$$

Dividing by uvf, we get

$$\Rightarrow \frac{uv}{uvf} = \frac{uf}{uvf} + \frac{vf}{uvf}$$

$$\Rightarrow \frac{1}{f} = \frac{1}{u} + \frac{1}{v} \quad \text{.....(4)}$$

Equation (4) is known as mirror formula.

Mirror formula for concave mirror when virtual image is formed:

Let an object AB is placed between the pole and the focus of a concave mirror of focal length 'f'. Also let A'B' be the virtual image formed by that mirror.

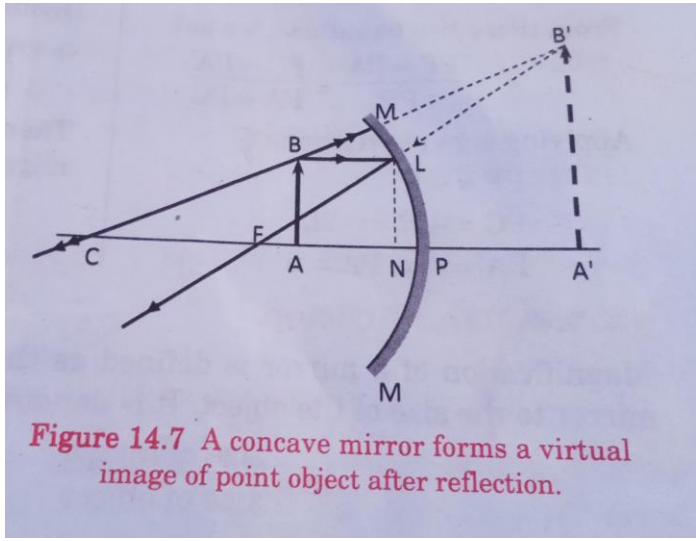


Figure 14.7 A concave mirror forms a virtual image of point object after reflection.

Draw LN perpendicular on the principal axis.

Now Δ's NLF and A'B'F are similar, and therefore

$$\frac{A'B'}{NL} = \frac{A'F}{NF}$$

Since aperture of the concave mirror is small , so the point N lies very close to P.

$$NF = PF$$

Also, $NL = AB$

And $$\frac{A'B'}{AB} = \frac{A'F}{PF} = \frac{PA'+PF}{PF}$$

Also Δ's ABC and A'B'C are similar , therefore

$$\frac{A'B'}{AB} = \frac{A'C}{AC} = \frac{PC+PA'}{PC-PA}$$

Combining these two ratios, we get

$$\frac{PA'+PF}{PF} = \frac{PC+PA'}{PC-PA}$$

Using sign convention

PA'=-v , PF=f , PC =R=2f

We have

$$\Rightarrow \frac{-v+f}{f} = \frac{-v+2f}{2f-u}$$

$$\Rightarrow uv - 2vf - uf + 2f^2 = 2f^2 - vf$$

$$\Rightarrow \text{ uv=uf+vf}$$

Dividing by uvf, we get

$$\Rightarrow \frac{uv}{uvf} = \frac{uf}{uvf} + \frac{vf}{uvf}$$

$$\Rightarrow \frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

Hence, it is a required expression.

Sketch the ray diagram in a concave mirror when an erect object is placed

a) At infinity
b) beyond the centre of curvature
c) at the centre of curvature
d) between the centre of curvature and the principal focus
e) at focus
f) between the pole and focus

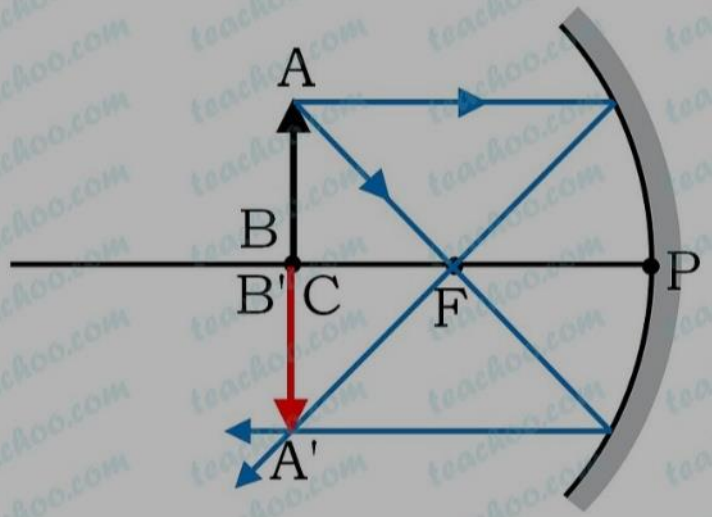
Also, write any two nature of the image formed.

Case 3 - Object is at Center of Curvature (C)

teachoo.com

Concave Mirror -

Object at Center of Curvature



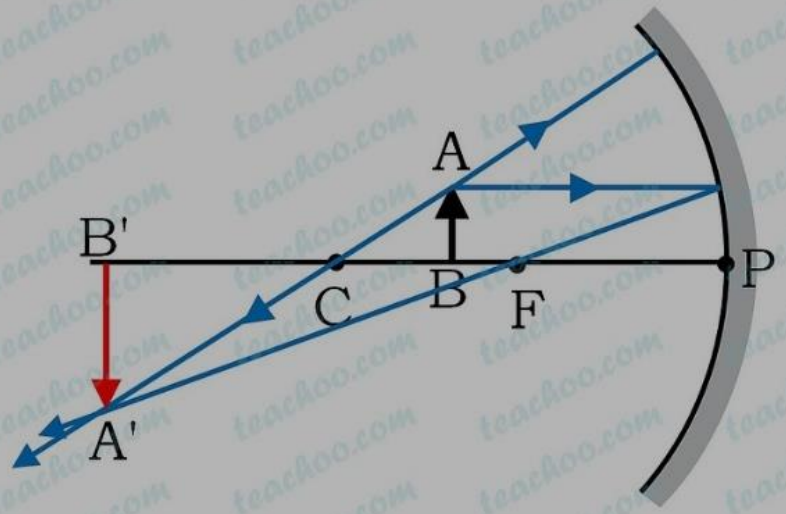
Nature: i) Real and inverted
ii) image is exactly the same size as that of object

Case 4 - Object is between Center of Curvature (C) and Focus (F)

teachoo.com

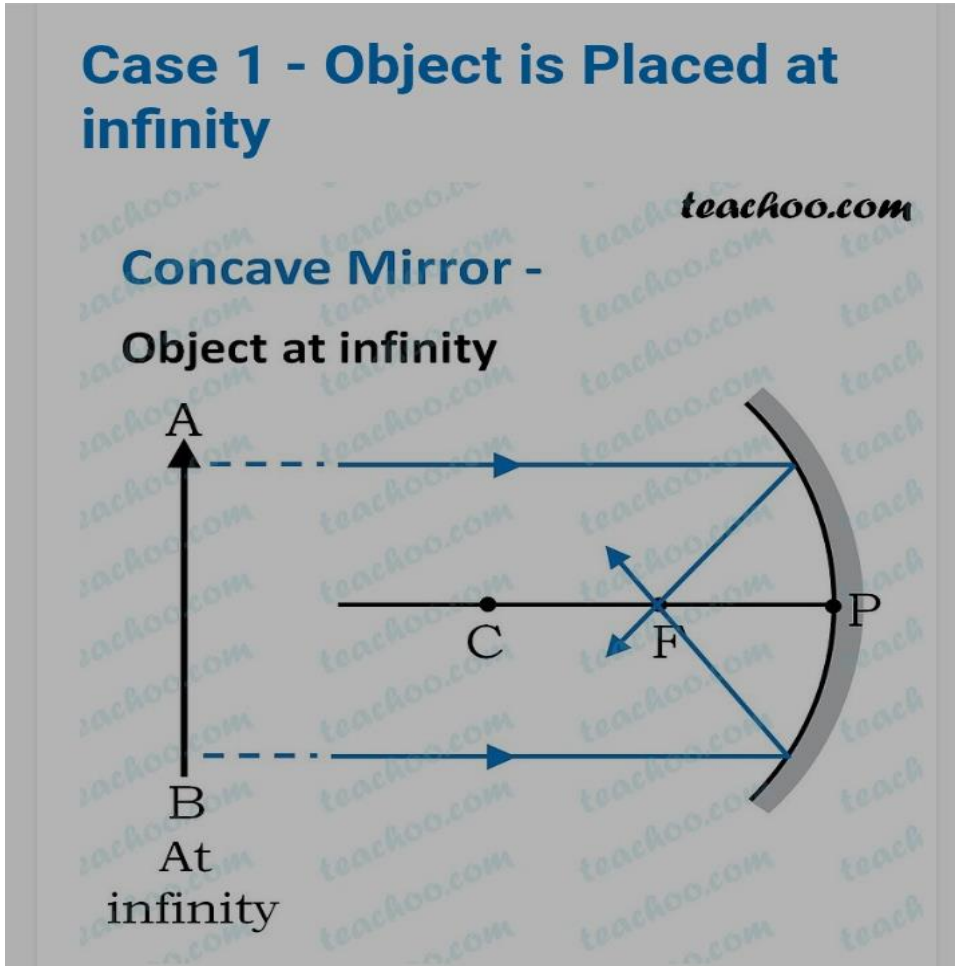
Concave Mirror -

Object between C & F



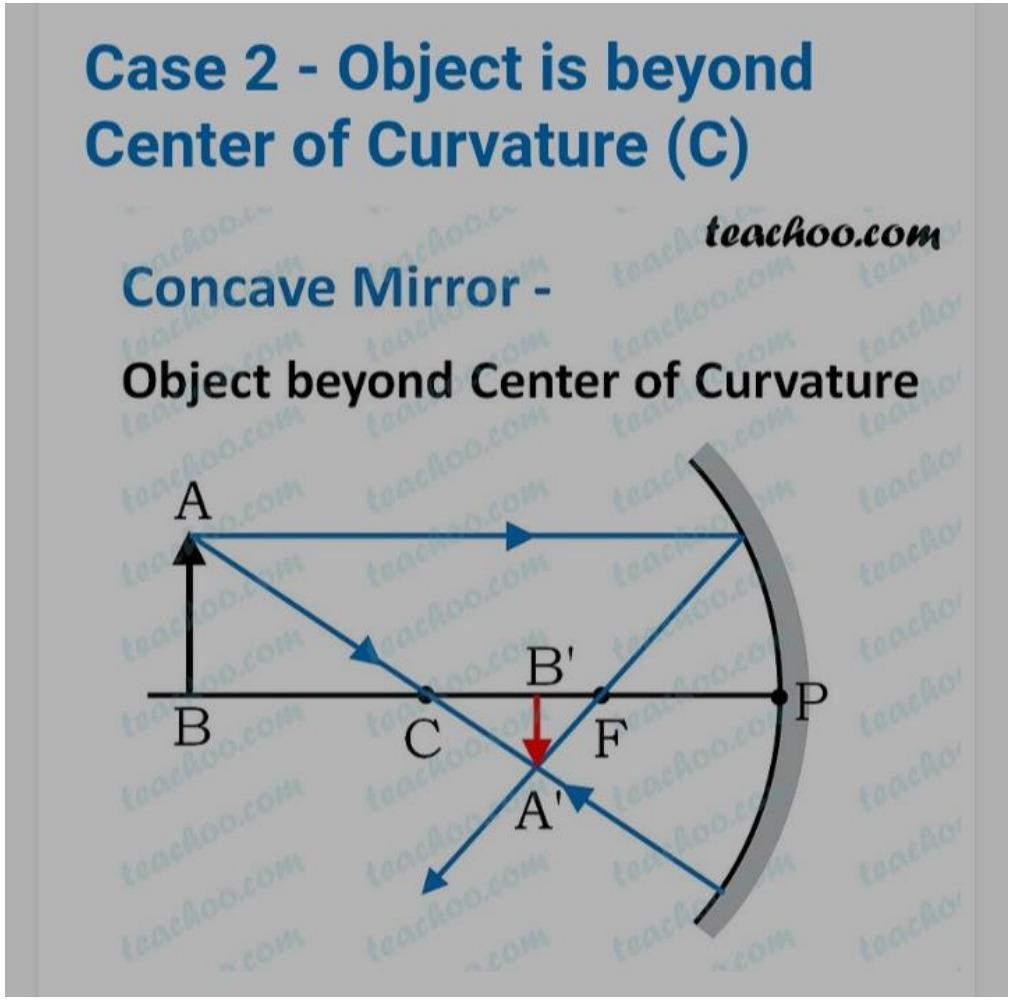
Nature: i) Real and inverted
ii) magnified image is formed

Case 1 - Object is Placed at infinity



Nature: i) Real and inverted
ii) highly diminished image is formed

Case 2 - Object is beyond Center of Curvature (C)



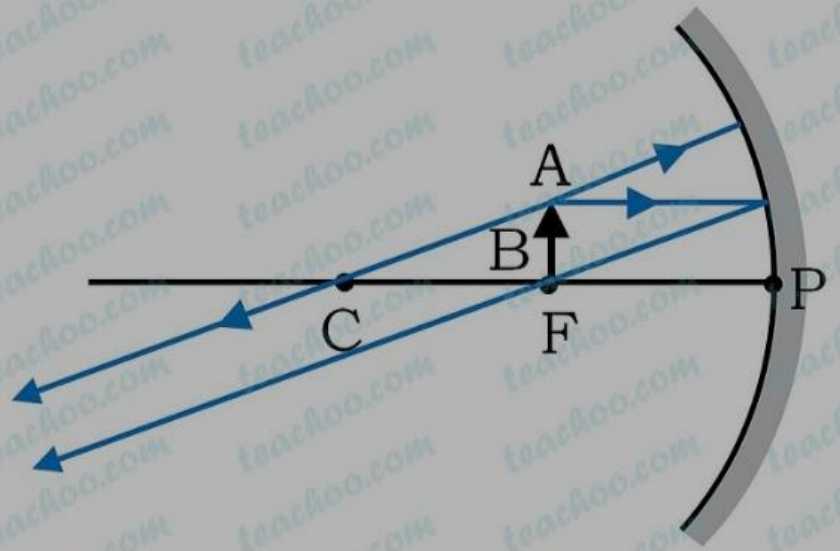
Nature: i) Real and inverted
ii) diminished image is formed

Case 5 - Object is at Focus (F)

teachoo.com

Concave Mirror -

Object at Focus



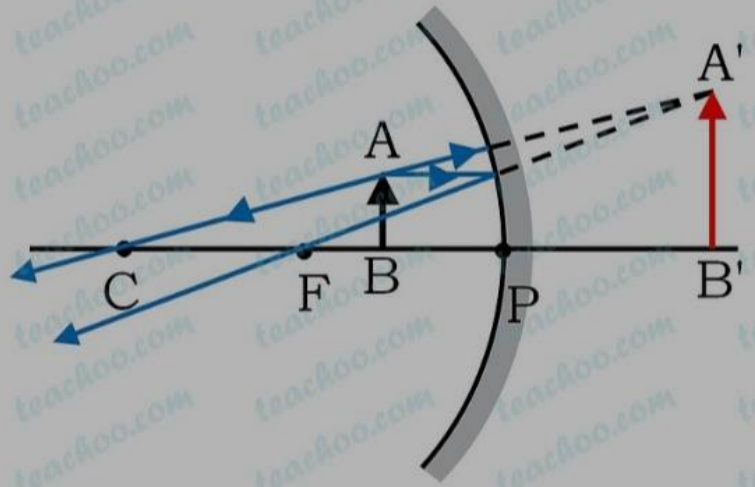
Nature: i) Real and inverted
ii) highly magnified image is formed

Case 6 - Object is between Pole (P) and Focus (F)

teachoo.com

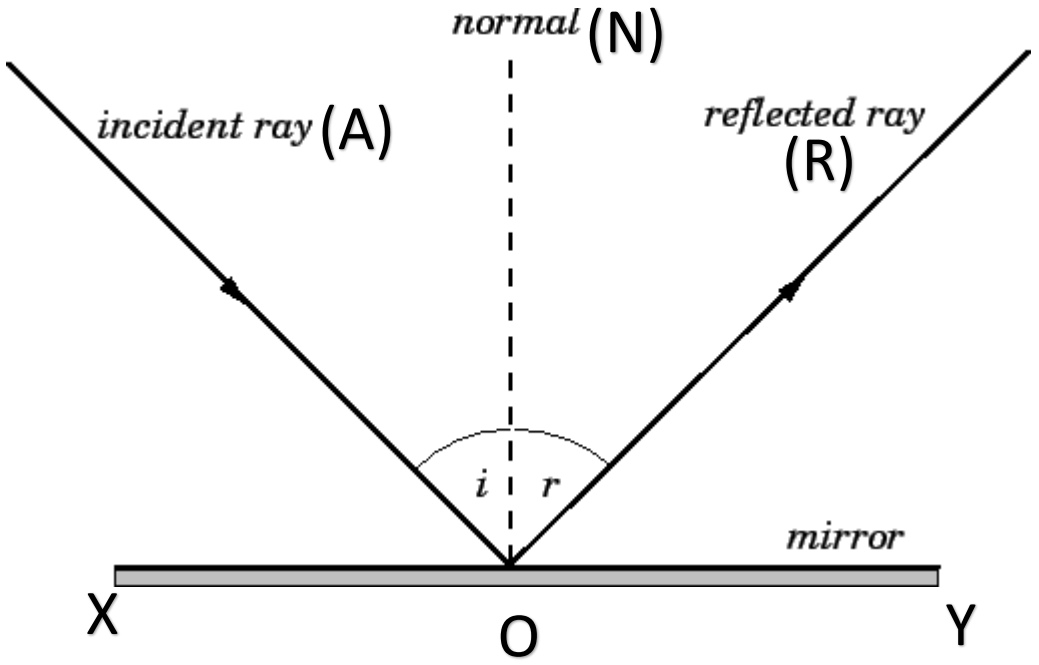
Concave Mirror -

Object between Pole (P) & Focus (F)



Nature: i) Virtual and erected
ii) magnified image is formed

Reflection of light: The phenomenon of turning back of light into the same medium from the surface of another medium is called reflection of light.



In the figure,

XY= reflecting surface

AO = incident ray

OR = reflected ray

ON = normal

∠AON = i = angle of incidence (incident angle)

∠RON =r= angle of reflection (reflected angle)

Laws of reflection of light:

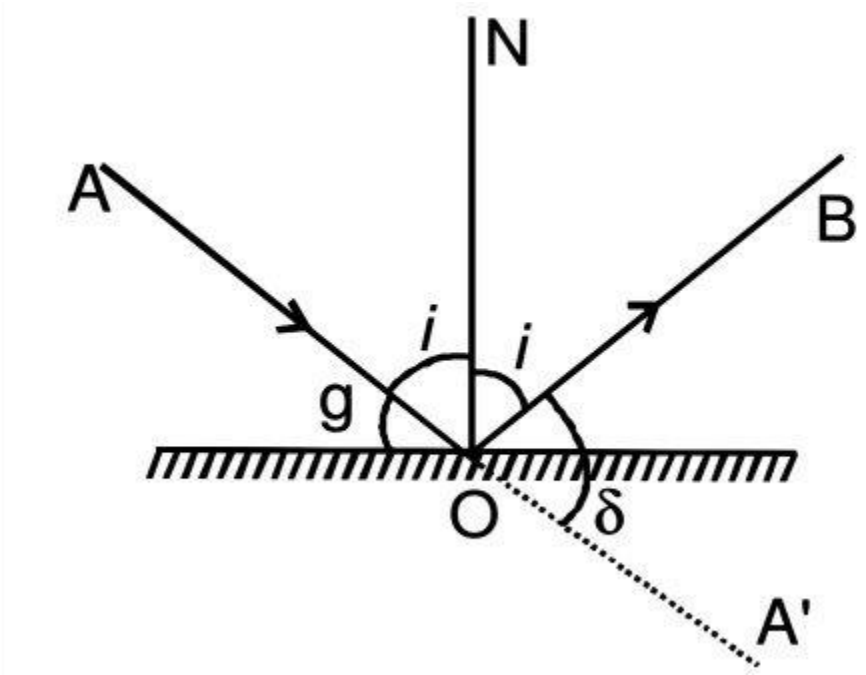
i) The incident ray, reflected ray and normal at the point of incident all lie in same plane.

ii) The angle of incidence is equal to the angle of reflection i.e. i =r.

Glancing angle (g) : The acute angle made by the incident ray with the reflecting surface is called glancing angle.

here, i=angle of incidence
r=angle of reflection
g=glancing angle

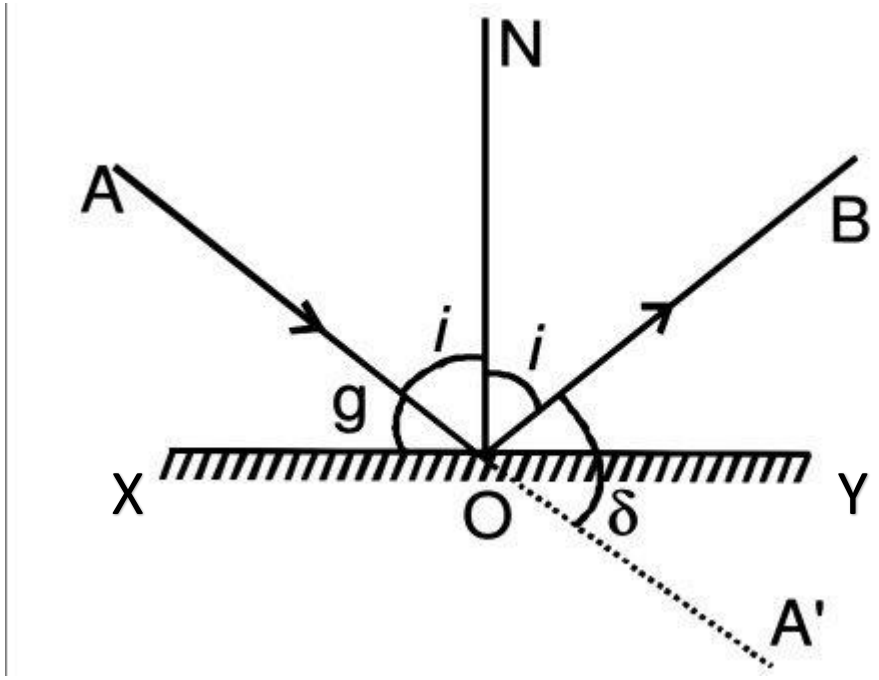
Angle of deviation (δ) : The angle between the reflected ray of light and the original direction of incident ray is called angle of deviation.



In the figure

∠A’OB = angle of deviation (δ)

Relation between angle of deviation (δ) and glancing angle :



From the figure; we have

⇒ ∠XON = ∠YON

⇒ ∠AOX + ∠AON = ∠BON+ ∠ BOY

⇒ g+i = ∠ BOY+ r

⇒ g= ∠ BOY (i = r , from laws of reflection)

Also , we have

$\Rightarrow \angle$ YOA' = $\angle$AOX

$\Rightarrow \angle$ YOA' = g

Again, we have

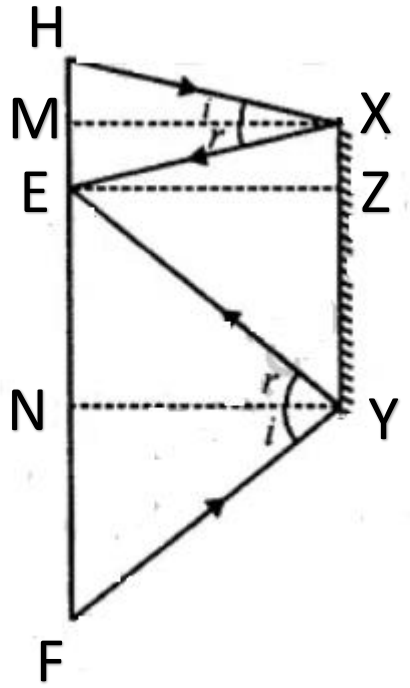
$\Rightarrow \angle$ BOA' = $\angle$ YOA'+ $\angle$ BOY

$\Rightarrow \delta = g + g$

$\Rightarrow \delta = 2g$

Minimum size of a plane mirror to see full size image of an object :

Consider a man (HF) is standing in front of a plane mirror (XY) as shown in figure. Here, points H, F and E correspond to head, feet and eye of the man respectively.



$\Rightarrow$ XY = XZ +ZY

=ME+EN

$= \frac{1}{2}$ HE + $\frac{1}{2}$ EF

$= \frac{1}{2}$ (HE+ EF)

$\Rightarrow$ XY $= \frac{1}{2}$ HF

Thus, the minimum size of plane mirror should be half of the size of object to see its full image in mirror.

Mirror formula for convex mirror :

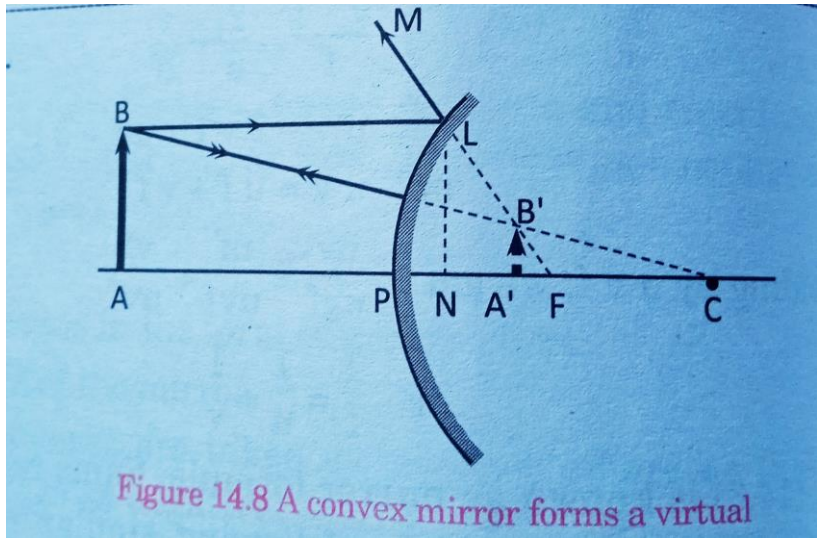


Figure 14.8 A convex mirror forms a virtual

Let an object AB is placed Infront of a convex mirror so that its image A'B' is formed as shown in figure.

Draw LN perpendicular on the principal axis.

Now Δ's NLF and A'B'F are similar, and therefore

$$\frac{A'B'}{NL} = \frac{A'F}{NF}$$

Since aperture of the convex mirror is small , so the point N lies very close to P.

$$NF = PF$$

Also, $$NL = AB$$

And $$\frac{A'B'}{AB} = \frac{A'F}{PF}$$

Also Δ's ABC and A'B'C are similar , therefore

$$\Rightarrow \frac{A'B'}{AB} = \frac{A'C}{AC}$$

Then, from these two equations , we get

$$\Rightarrow \frac{A'F}{PF} = \frac{A'C}{AC} \quad \text{.....(1)}$$

$$\Rightarrow \frac{PF-PA'}{PF} = \frac{PC-PA'}{PA+PC} \quad \text{.....(2)}$$

But, PA= u (object distance) , PA'= -v (image distance), PF=-f, PC =-R= -2f

Hence , equation (2) becomes

$$\Rightarrow \frac{-f+v}{-f} = \frac{-2f+v}{u-2f} \quad \text{.....(3)}$$

$$\Rightarrow -uf + 2f^2 + uv - 2vf = 2f^2 - vf$$

$$\Rightarrow \text{ uv=uf+vf}$$

Dividing by uvf, we get

$$\Rightarrow \frac{uv}{uvf} = \frac{uf}{uvf} + \frac{vf}{uvf}$$

$$\Rightarrow \frac{1}{f} = \frac{1}{u} + \frac{1}{v} \quad \ldots\ldots\ldots\

$$\frac{O'B'}{OB} = \frac{O'P}{OP} = \frac{v}{u}$$

From definition,

$$m = \frac{O'B'}{OB} = \frac{v}{u}$$

Magnification can be expressed in terms of u and v also.
We have,

$$\Rightarrow \frac{1}{f} = \frac{1}{u} + \frac{1}{v} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Multiplying both sides by u in above equation, we get

$$\Rightarrow \frac{u}{f} = \frac{u}{u} + \frac{u}{v}$$

$$\Rightarrow \frac{u}{f} = 1 + \frac{1}{v/u}$$

$$\Rightarrow \frac{u}{f} = 1 + \frac{1}{m}$$

$$\Rightarrow m = \frac{f}{u-f}$$

Similarly, multiplying both sides by v in equation (1), we get

$$\Rightarrow \frac{1}{f} = \frac{1}{u} + \frac{1}{v} \quad \ldots\ldots\ldots\

Magnification (m) of convex mirror:

Let an object OB is placed in-front of a convex mirror so that its virtual image O'B' is formed by the mirror as shown in figure.

Here, Δ's BPO and B'PO' are similar , therefore

$$\frac{O'B'}{OB} = \frac{O'P}{OP} = \frac{-v}{u}$$ (since image is virtual.)

From definition,

$$m = \frac{O'B'}{OB} = \frac{-v}{u}$$

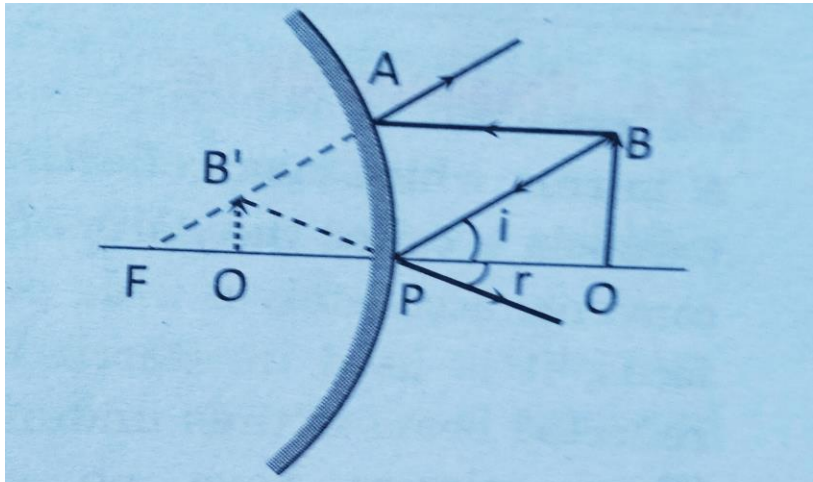
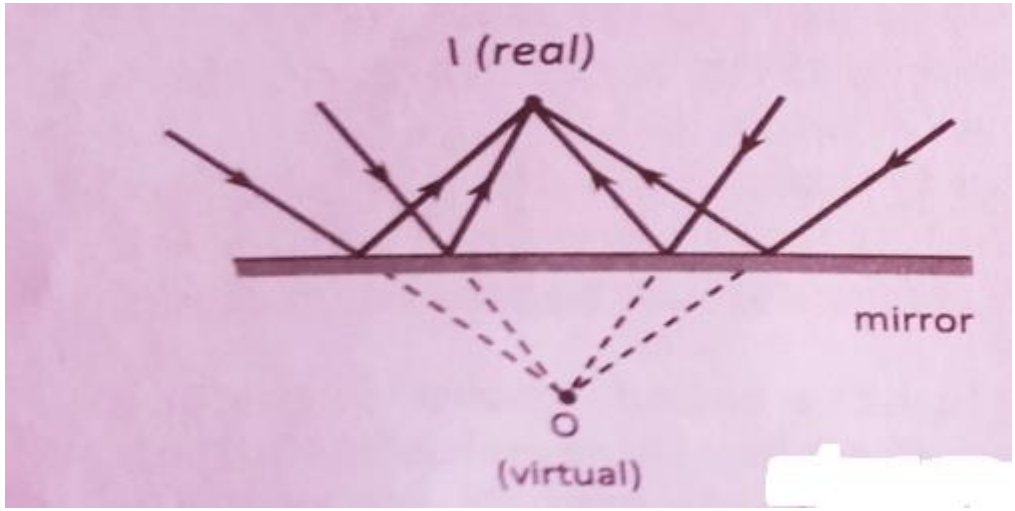


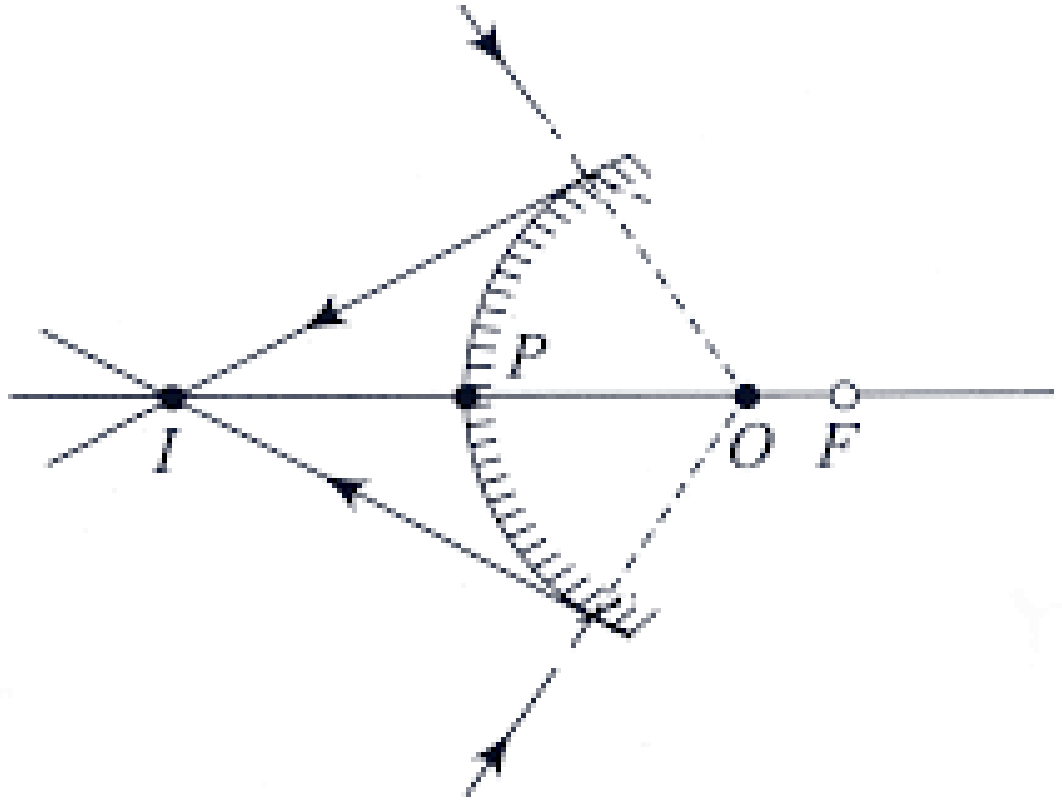
Figure 14.10 Virtual diminished image produces by convex mirror.

Q.1) Can a plane mirror ever form a real image, Explain with figure?



Yes, real image can be formed in a plane mirror. When a converging beam of light incident in a plane mirror, real image is formed as shown in figure. For this case object must be virtual.

Q.2) Can a convex mirror ever form a real image, Explain with figure?



Yes, real image can be formed in a convex mirror. When a converging beam of light incident in a plane mirror, real image is formed as shown in figure. For this case object must be virtual.

Q.3) A spherical mirror is immersed in water, will its focal length change?

No, its focal length will not be changed when it is immersed in water. As we know, radius of curvature does not change when immersed in water. As, $F \propto R$, when radius remains unchanged , focal length will also not be changed.

OR,

No, the focal length of a spherical mirror does not change when it is immersed in water because the focal length of mirror is independent to the medium in which it is kept. As,

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

,it is independent of refractive index of medium. So, the focal length of mirror does not change when it is kept in water.

Q.4) What type of mirror will you suggest for shaving or makeup purposes? Explain why?

I will suggest concave mirror for shaving or make up purpose because it forms an erect and enlarged image if the object is placed between its pole and focus.

Q.5) For driving a car what type of mirror would you prefer?

Since a convex mirror has wide field of view, it produces image of a large area. It gives virtual, erect, and small size of image so that all the images can be seen clearly. Hence, a convex mirror is used as driving mirror.

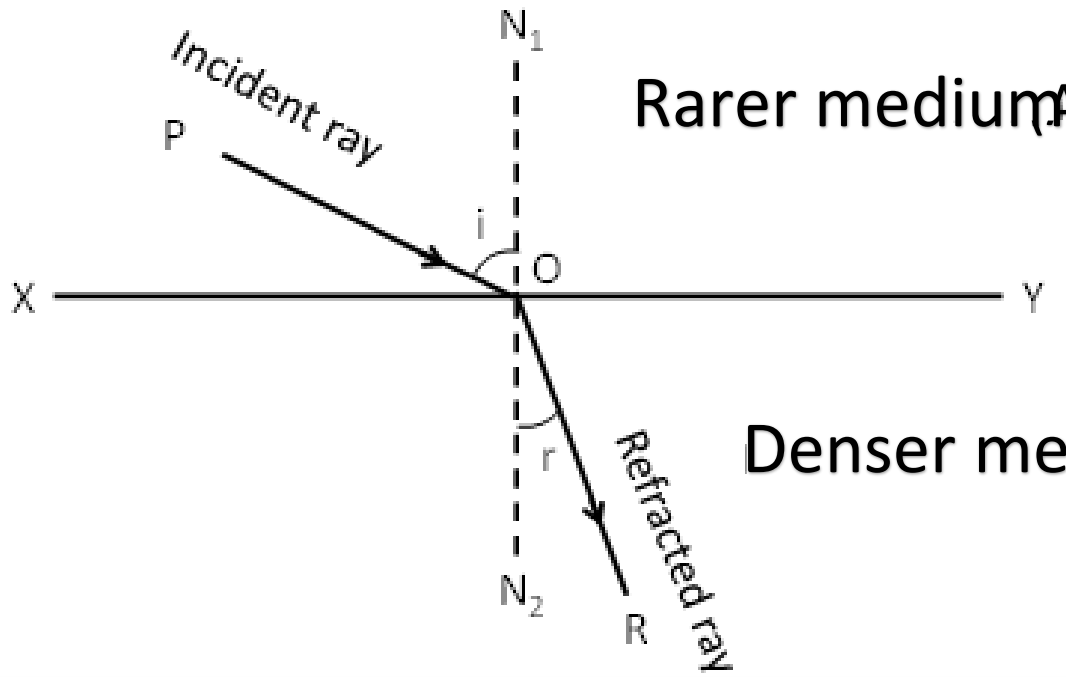
New Capital College

Class 11-Physics
Optics

Chapter-15
Refraction at Plane Surface

Refraction of light: The phenomenon of bending of light when it travels from one optical medium to another optical medium.

When the light ray travels from rarer to denser medium, it bends towards the normal.

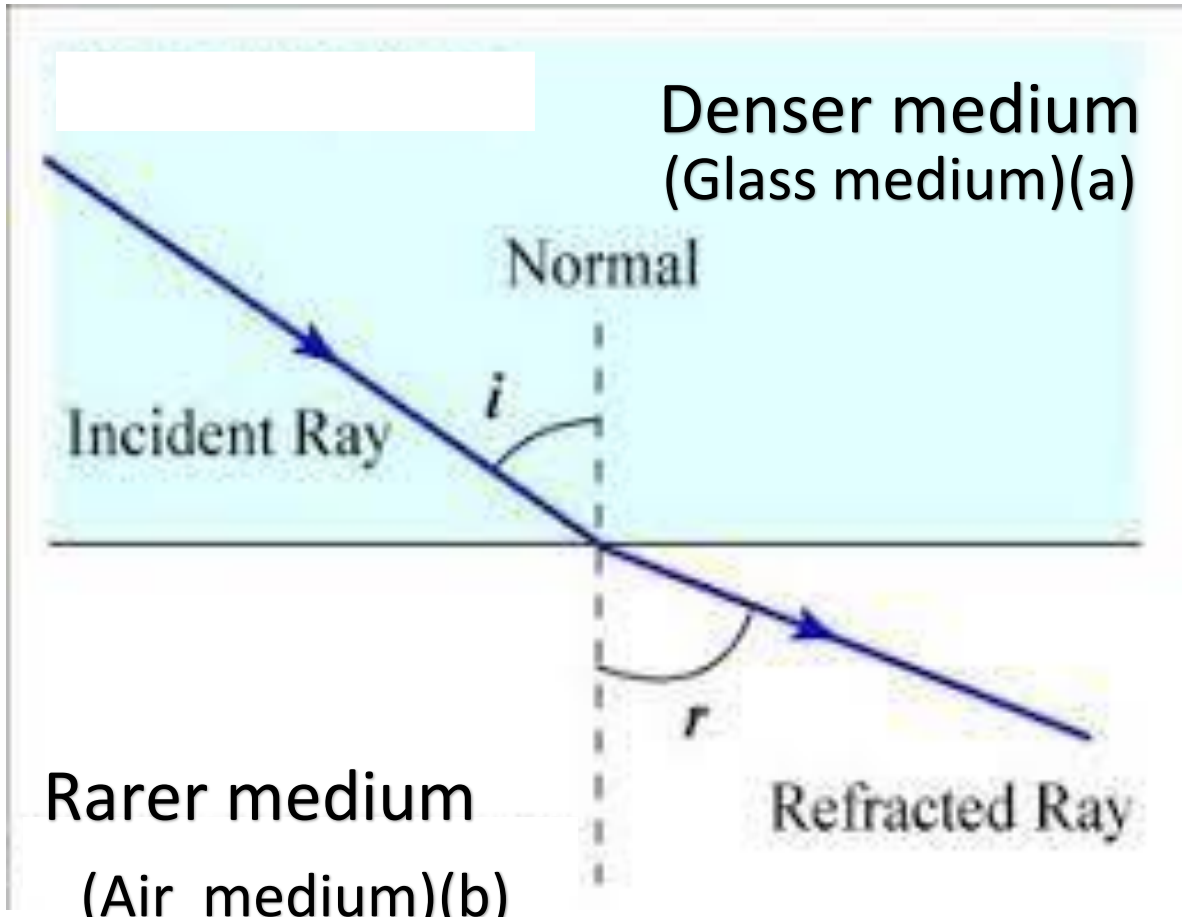


Rarer medium (Air medium) (a)

Denser medium (Glass medium)(b)

Where, i>r

When the light ray travels from denser to rarer medium, it bends away from the normal.



Where, i<r

Law of Refraction of light:

1. The incident ray, refracted ray and the normal to the point of incidence all lie in the same plane.
2. The ratio of sine of angle of incidence to the sine of angle of refraction is always a constant and is called refractive index. This is also called Snell's law.

$$a\mu b = \frac{\sin i}{\sin r} = \text{constant}$$

Where,
$a\mu b$ is called refractive index of medium b with respect to medium a.

Absolute refractive index (μ):

The ratio of velocity of light in vacuum to the velocity of light in a medium is called absolute refractive index of medium.

$$\Rightarrow \mu = \frac{\text{velocity of light in vacuum (C)}}{\text{velocity of light in medium (V)}}$$

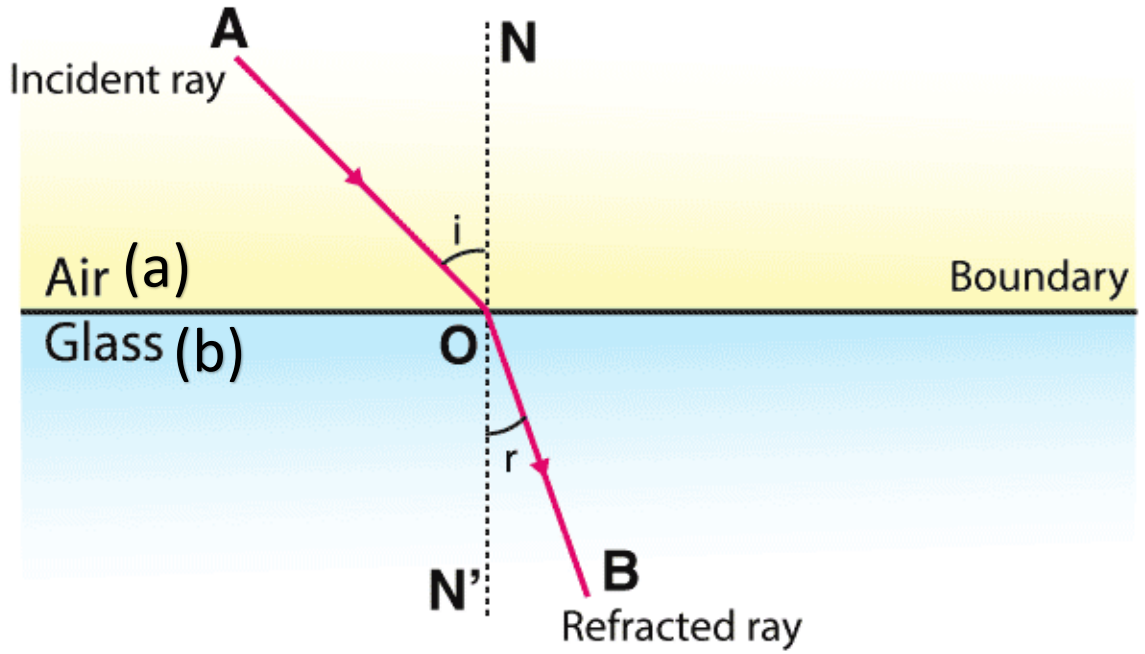
Where, C= $3 * 10^8$ m/s

Note:

$$a\mu b = \frac{\text{velocity of light in medium 'a'}}{\text{velocity of light in medium 'b'}}$$

Relation between refractive indices:

a) Relation between two refractive indices:



Consider two mediums air (a) and glass (b) as shown in figure. When the light ray travels from air (a) to glass (b) ,then from the Snell's law, we have

$$\Rightarrow a\mu b = \frac{\sin i}{\sin r} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Now, if the path of light is reversed i.e. from glass (b) to air (a), then from the principle of reversibility of light , we have

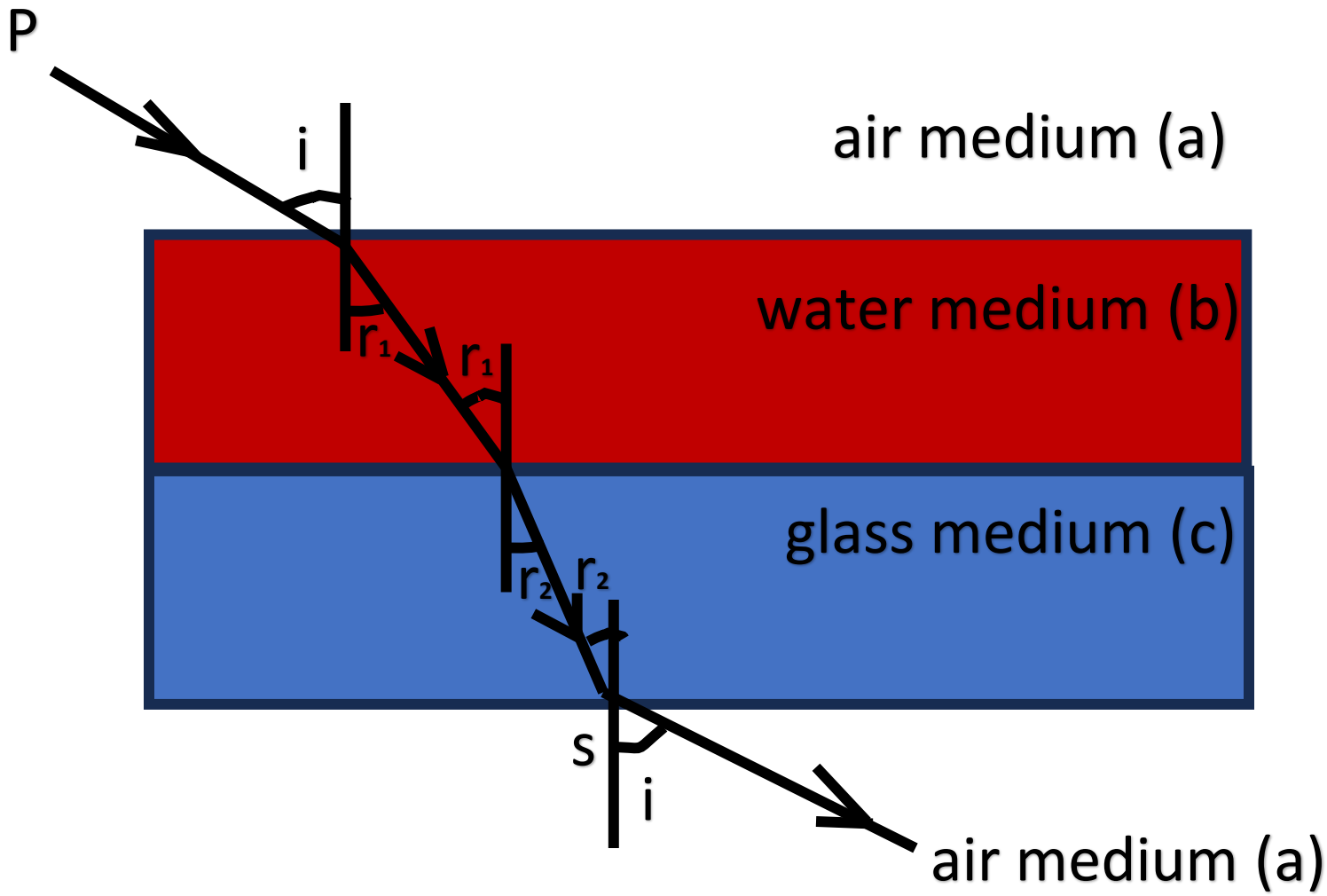
$$\Rightarrow b\mu a = \frac{\sin r}{\sin i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Multiplying equation (1) and (2), we get

$$\Rightarrow a\mu b^{*}\, b\mu a = \frac{\sin i}{\sin r} * \frac{\sin r}{\sin i} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

$$\Rightarrow a\mu b^{*}\, b\mu a = 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

b) Relation between three refractive indices (Refraction through a compound plate):



Here, when the light ray travel from air (a) to water (b) then, from Snell's law,

$$\Rightarrow a\mu b = \frac{\text{Sin i}}{\text{sinr}_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Similarly, when the light ray travel from water (b) to glass (c) then, from Snell's law,

$$\Rightarrow b\mu c = \frac{\text{sinr}_1}{\text{Sinr}_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Again, when the light ray travel from glass (c) to air (a) , we have

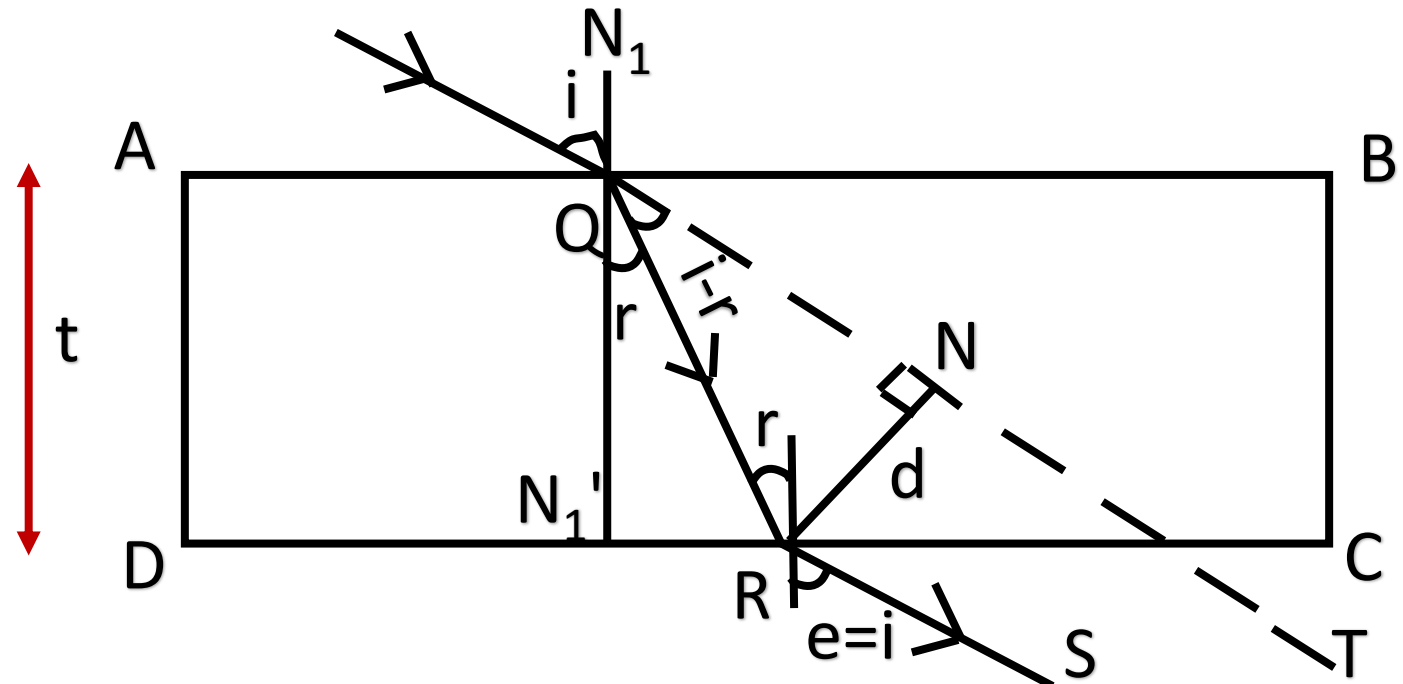
$$\Rightarrow c\mu a = \frac{\text{Sinr}_2}{\text{Sin i}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

now, multiplying equation (1), (2) and (3) , we get

$$\Rightarrow a\mu b * b\mu c * c\mu a = \frac{\text{Sin i}}{\text{sinr}_1} * \frac{\text{sinr}_1}{\text{Sinr}_2} * \frac{\text{Sinr}_2}{\text{Sin i}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

$$\Rightarrow a\mu b * b\mu c * c\mu a = 1\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Lateral Shift: When light ray passes from one medium to another medium, it bends from its original path. The perpendicular distance between the emergent ray and the original direction of incident ray is called lateral shift.



Consider a rectangular glass slab of thickness ‘t ‘ is as shown in figure. Let PQ is an incident ray , QR is refracted ray and RS is an emergent ray.

Now, from Δ RNQ,

$$\Rightarrow \sin(i-r) = \frac{RN}{QR}$$

$$\Rightarrow RN = QR\sin(i-r) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (i)$$

Again, from Δ QRN_1',

$$\Rightarrow \cos r = \frac{QN_1'}{QR}$$

$$\Rightarrow QR = \frac{t}{\cos r} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (ii)$$

Where QN_1'= t = thickness of slab

Now, from equations (i) and (ii) we get

$$\Rightarrow RN = \frac{t}{\cos r}\sin(i-r)$$

$$\Rightarrow \text{Lateral shift (d)} = \frac{t}{\cos r} \sin(i - r)$$

This is the required expression for lateral shift.

When i=90°, we get

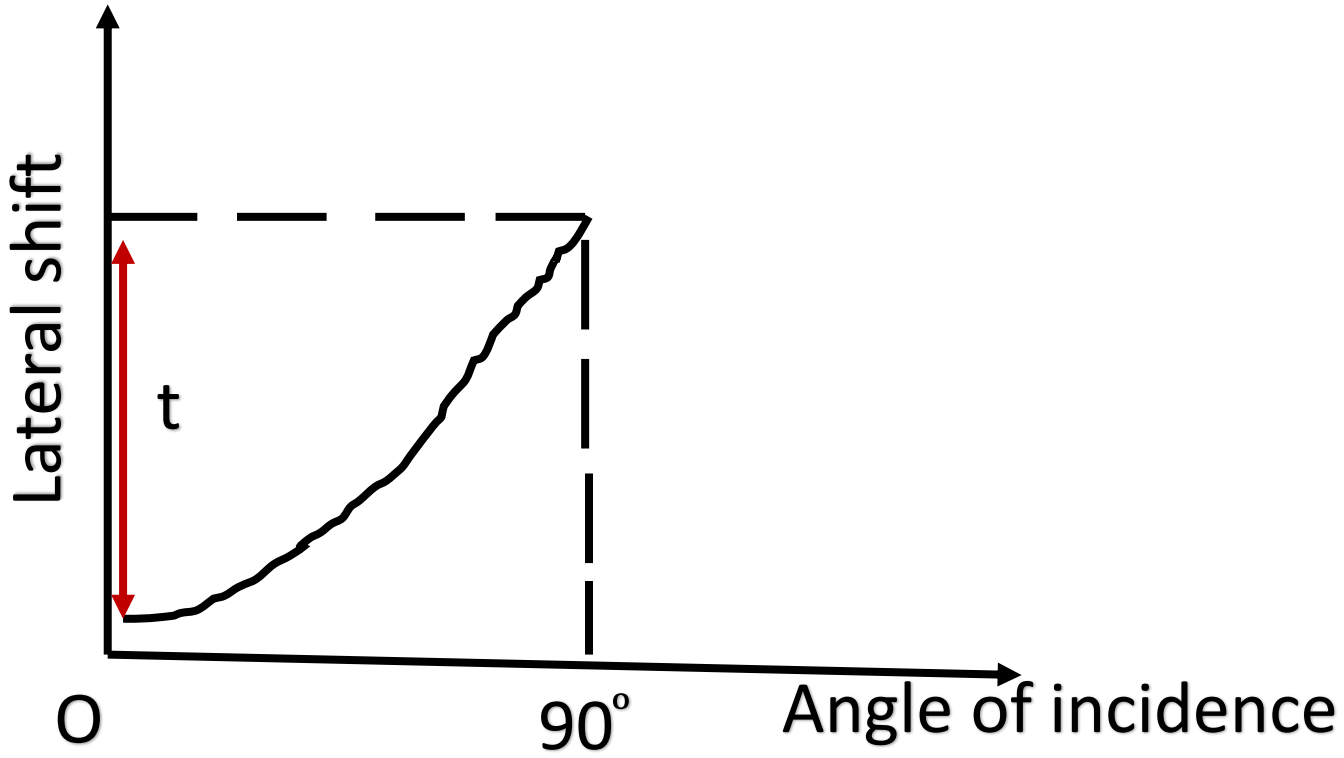
$$\Rightarrow \text{Lateral shift (d)} = \frac{t}{\cos r} \sin(90° - r)$$

$$\Rightarrow \text{Lateral shift (d)} = \frac{t}{\cos r} \cos r$$

$$\Rightarrow \text{Lateral shift (d)} = t$$

Thus, lateral shift is equal to the thickness of glass slab when the angle of incidence is 90°

The variation of lateral shift with angle of incidence is shown in graph below:



lateral shift depends on:

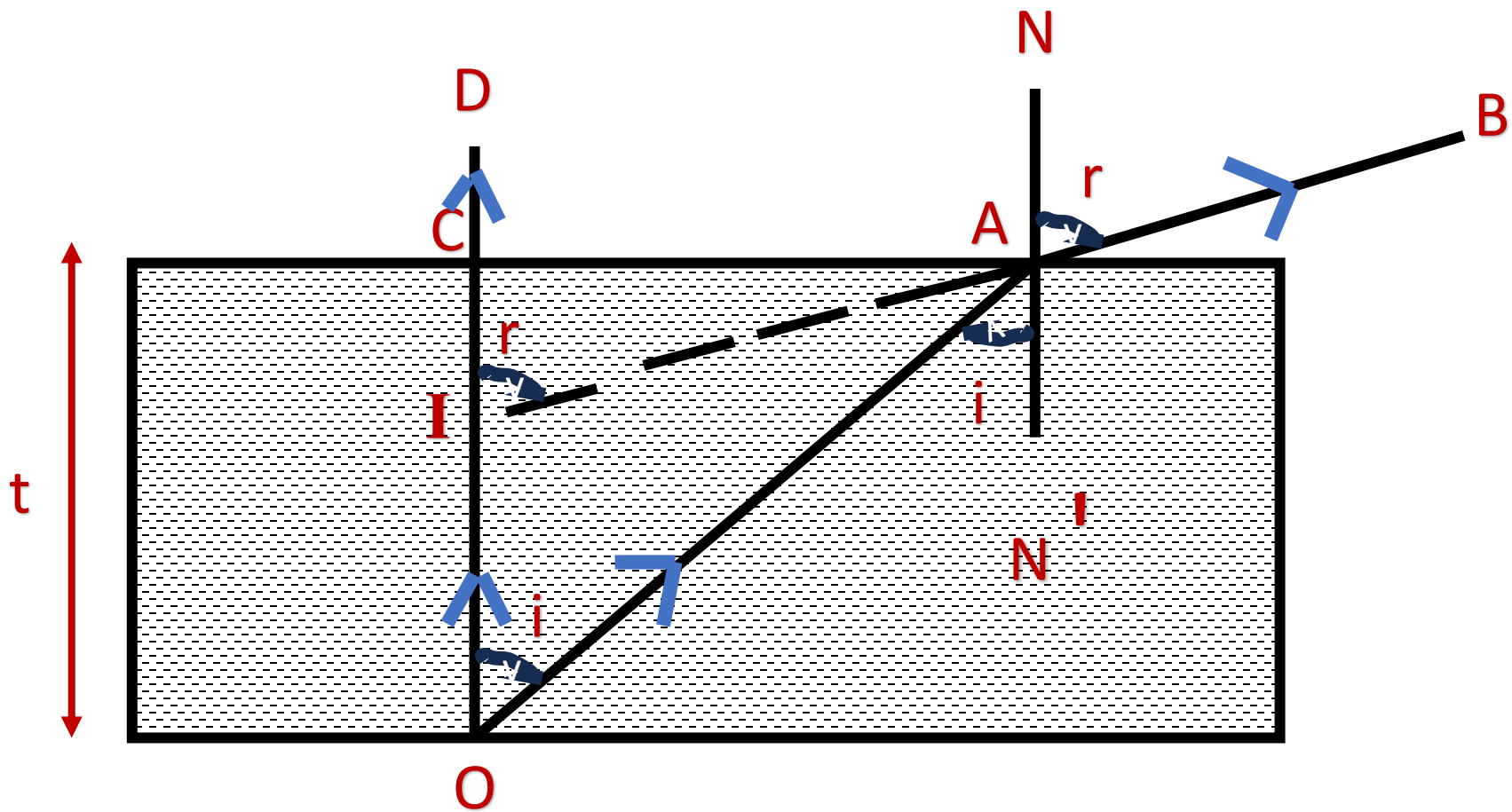
(i) Thickness of slab

(ii) Angle of incidence

(iii) Refractive index of material of slab and that of the surrounding

(iv) Wavelength of light used

Real and Apparent Depth:



When an object is placed in a denser medium and viewed from a rarer medium above the denser medium, it appears to be at a lesser depth than its real depth. This is due to refraction of light.

Let a point object “O” is at the bottom of water with real depth “t” as shown in figure.

Let a ray of light OC is incident normally at point “C” on water –air interface and emerge along CD. Another ray of light OA is incident at point “A” on water –air interface making incident angle ∠ OAN’ =i and is refracted along AB making refracted angle ∠ NAB =r.

An observer see the point “O” raised up to an apparent position “I” when viewed from above.

In the figure,

OC=t=real depth

IC=apparent depth

Now, from Snell's law, we have

$$\Rightarrow w\mu a = \frac{\sin i}{\sin r}$$

$$\Rightarrow \frac{1}{a\mu w} = \frac{\sin i}{\sin r}$$

$$\Rightarrow a\mu w = \frac{\sin r}{\sin i} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(i)}$$

From ΔOCA, we have

$$\Rightarrow \sin i = \frac{CA}{OA} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(ii)}$$

From ΔOCA, we have

$$\Rightarrow \sin r = \frac{CA}{IA} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(iii)}$$

Now, using equations (ii) and (iii) in equation (i), we get

$$\Rightarrow a\mu w = \frac{CA}{IA} * \frac{OA}{CA}$$

$$\Rightarrow a\mu w = \frac{OA}{IA} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(iv)}$$

But for small angle of incidence

$A \Rightarrow C$ and $OA \approx OC$, $IA \approx IC$

Thus,

$$\Rightarrow a\mu w = \frac{OC}{IC}$$

$$\Rightarrow \text{Refractive Index}(a\mu w) = \frac{\text{Real depth}}{\text{Apparent depth}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(v)}$$

And the apparent displacement in the position of the object is

$$\Rightarrow OI = OC - IC = OC - \frac{OC}{a\mu w} = OC\left(1 - \frac{1}{a\mu w}\right)$$

$$\Rightarrow \text{Displacement(d)} = t\left(1 - \frac{1}{a\mu w}\right)$$

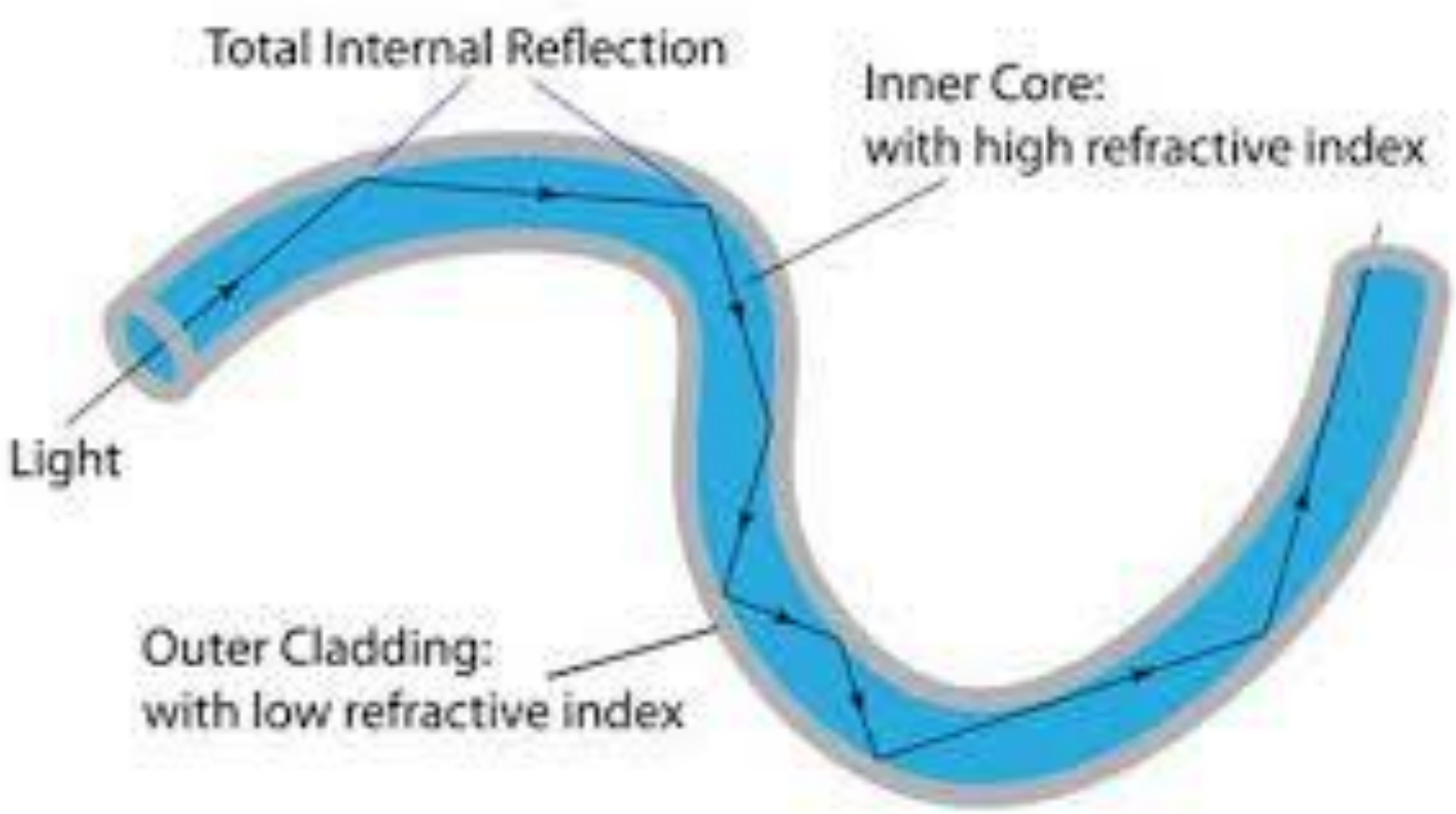
$$\Rightarrow \text{Apparent displacement} = \text{real depth}\left(1 - \frac{1}{\text{refractive index}}\right)$$

Optical Fibre (Light pipe)

An optical fibre is a glass or plastic fibre through which light is transmitted from one end to another end due to total internal reflection. The fibre is usually surrounded by a transparent cladding of lower refractive index than the core. Total internal reflection takes place in the core-cladding interface.

A ray of light entering from one end of the fibre suffers multiple total internal reflection along the rod due to large value of incident angle compared to critical angle. Thus, light can be transmitted to large distances without the loss of intensity.

When bundles of optical fibres are tapped together, a flexible pipe is obtained called light pipe.


Total Internal Reflection
Inner Core:
with high refractive index
Light
Outer Cladding:
with low refractive index

Applications of optical Fibre (Light pipe)

1. Optical fibre are used in transmitting and receiving electrical signals in telecommunication.
2. Light pipes is used to see the internal parts of the body like stomach, intestine, etc.

SAQ

1. What is the cause of refraction of light when it passes from one medium to another?

The refraction of light occurs because light travels at different speeds in different media. The speed of light is maximum in vacuum. when light passes from air to an optically denser medium , it speed decreases and vice versa. Due to this change in the speed of light , refraction takes place.

1. Will the sparkling of diamond change if it is dipped in transparent oil?

When the diamond is dipped into the transparent oil, the relative refractive index decreases and the critical angle increases so that sparkling is reduced due to less number of total internal reflection.

2. Can light travelling from air to glass suffer total internal reflection ? Justify your answer.

No, This is because one of the necessary conditions for total internal reflection is that the incident light should be in denser medium.

3. Does critical angle depend on colour of light?

Yes, as $\sin c = 1/\mu$ i.e., c depends on μ, but μ depends on wavelength λ. Hence, critical angle, c depends on colour of light.

4. Why does the rising sun appear bigger?

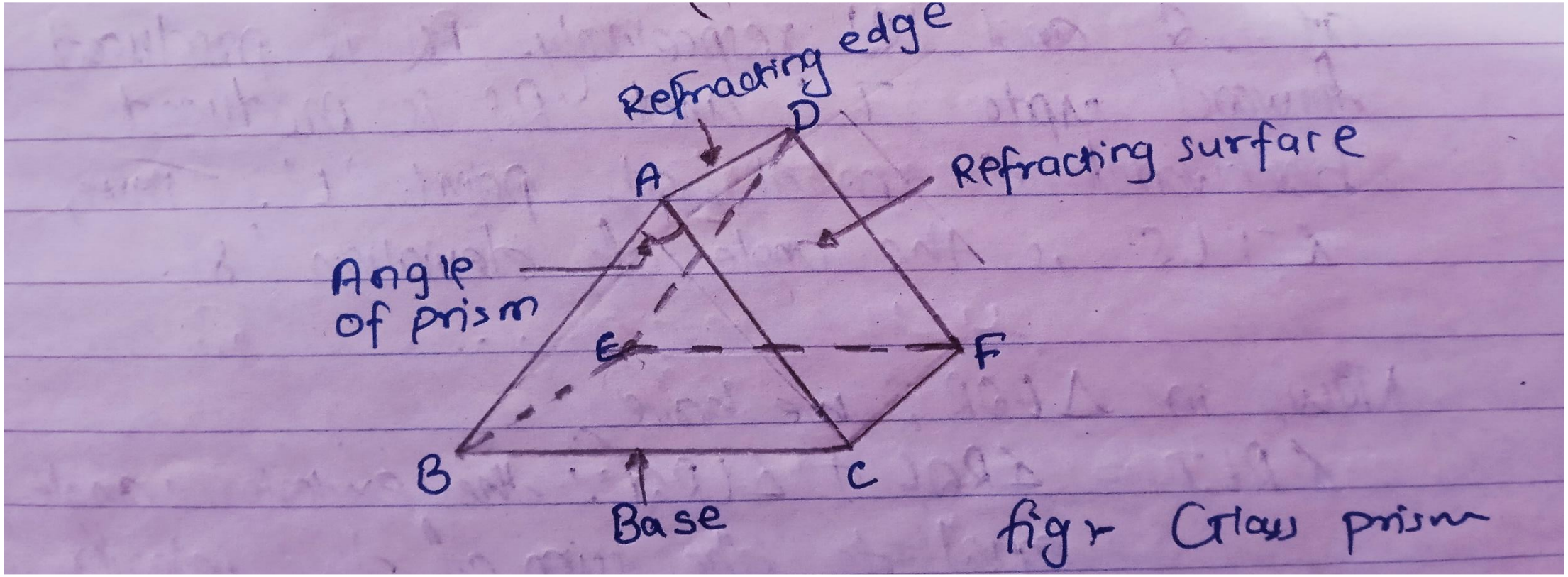
Light from the rising sun reaches the earth's surface obliquely through different parts of the earth's atmosphere , suffering unequal refractions. The vertical diameter appears shorter and the horizontal diameter appears bigger. Therefore, the rising sun appears oval and bigger.

Chapter 16: Refraction Through Prisms

Prism:

A prism is a wedge-shaped transparent refracting medium having two triangular faces and three rectangular faces.

The angle between two refracting faces of the prism is called the angle of prism.



Relation between angle of prism, minimum deviation and refractive index of the prism:

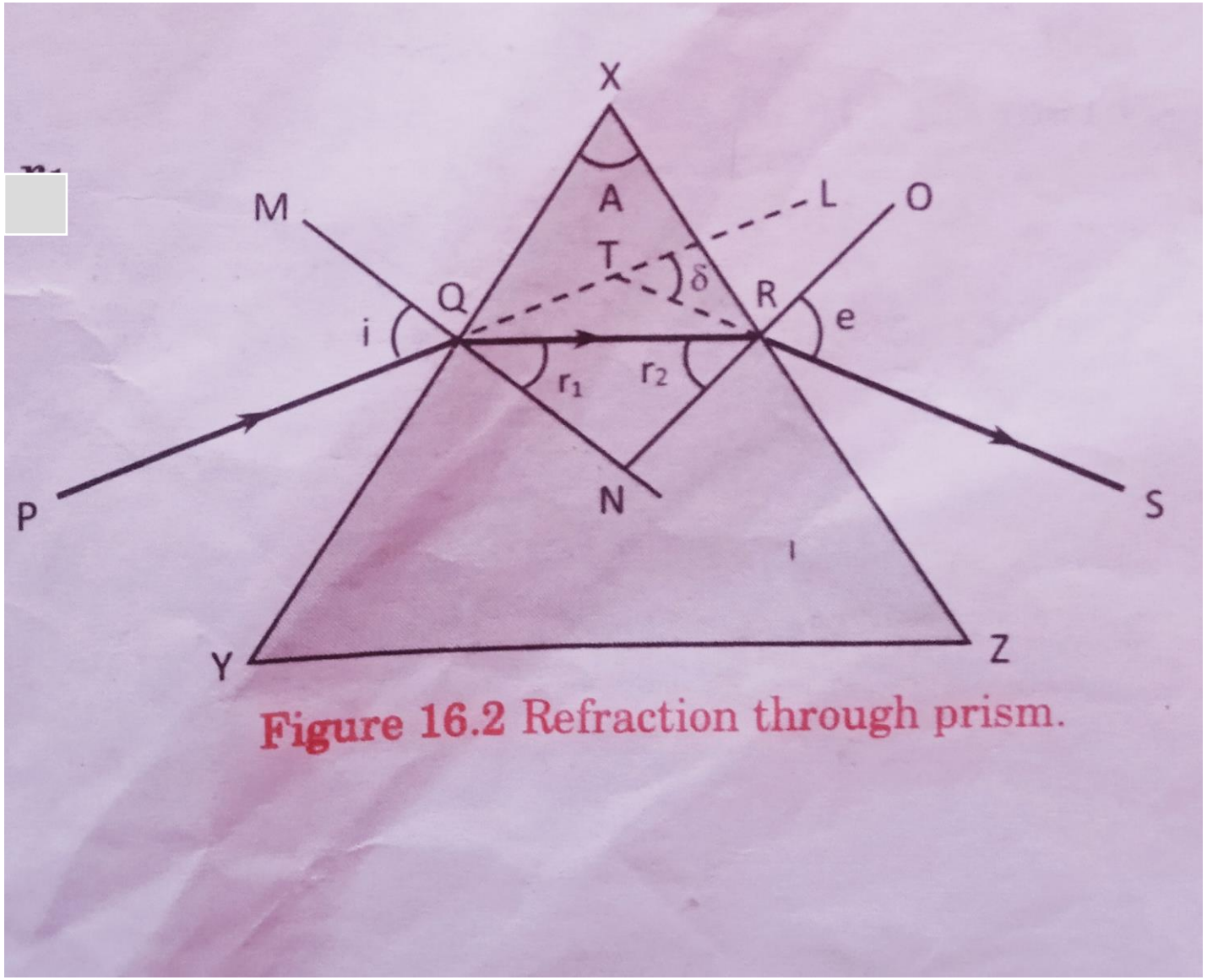


Figure 16.2 Refraction through prism.

Consider a principal section XYZ of a glass prism having angle of prism 'A'. Let a ray of light PQ is incident at an angle of incidence 'i' on the face 'XY' of the prism and refracted along QR in the glass making refracted angle 'r_1' as shown in figure. QR is, in its turn, incident on the face XZ of the prism making incident angle 'r_2' and refracted along RS in air making emergent angle 'e'.

Here, MN and ON are the normal drawn on the face XY and XZ respectively. Here, $\angle RTL$ is angle of deviation 'δ'.

The angle of deviation produced at the first face

$$\Rightarrow \delta_1 = \angle TQR$$

$$= \angle TQN - \angle RQN = i - r_1$$

And that produced at the second face

$$\Rightarrow \delta_2 = \angle TRQ$$

$$= \angle TRN - \angle QRN = e - r_2$$

the net deviation produced by the prism is

$$\Rightarrow \delta = \delta_1 + \delta_2 = \angle RTL$$ [the exterior angle of triangle is equal to the sum of two interior opposite angle]

$$\Rightarrow \delta = i - r_1 + e - r_2$$

$$\Rightarrow \delta = i + e - (r_1 + r_2) \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

In Δ QRN,

$$\Rightarrow r_1 + r_2 + \angle RNQ = 180^\circ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

In quadrilateral QXRN,

$$\Rightarrow \angle QXR + \angle XRN + \angle RNQ + \angle NQX = 360^\circ$$

$$\Rightarrow A + 90^\circ + \angle RNQ + 90^\circ = 360^\circ$$

$$\Rightarrow A + \angle RNQ = 180^\circ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

From equations (2) and (3) ,

$$\Rightarrow A = r_1 + r_2$$

Substituting this value in equation (1) , we obtain

$$\Rightarrow \delta = i+e-A \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$\Rightarrow \delta + A = i+e \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Thus, the sum of angle of deviation and angle of prism is equal to the sum of the angle of incidence and angle of emergence.

Condition for minimum deviation:

If we go on increasing the value of incidence , angle of deviation first decreases, then attains the minimum value and then starts to increases. That particular value of angle of deviation at which its value will be minimum is called angle of minimum deviation. It is denoted by 'δm'.

The angle of deviation will be minimum when angle of incidence is equal to the angle of emergence, refracted angle on the first face is equal to the incident angle for the second face and refracted light inside the prism is parallel to the base of prism.

i.e. For $\delta = \delta m \Rightarrow i = e$ and $r_1 = r_2 = r$ (say)

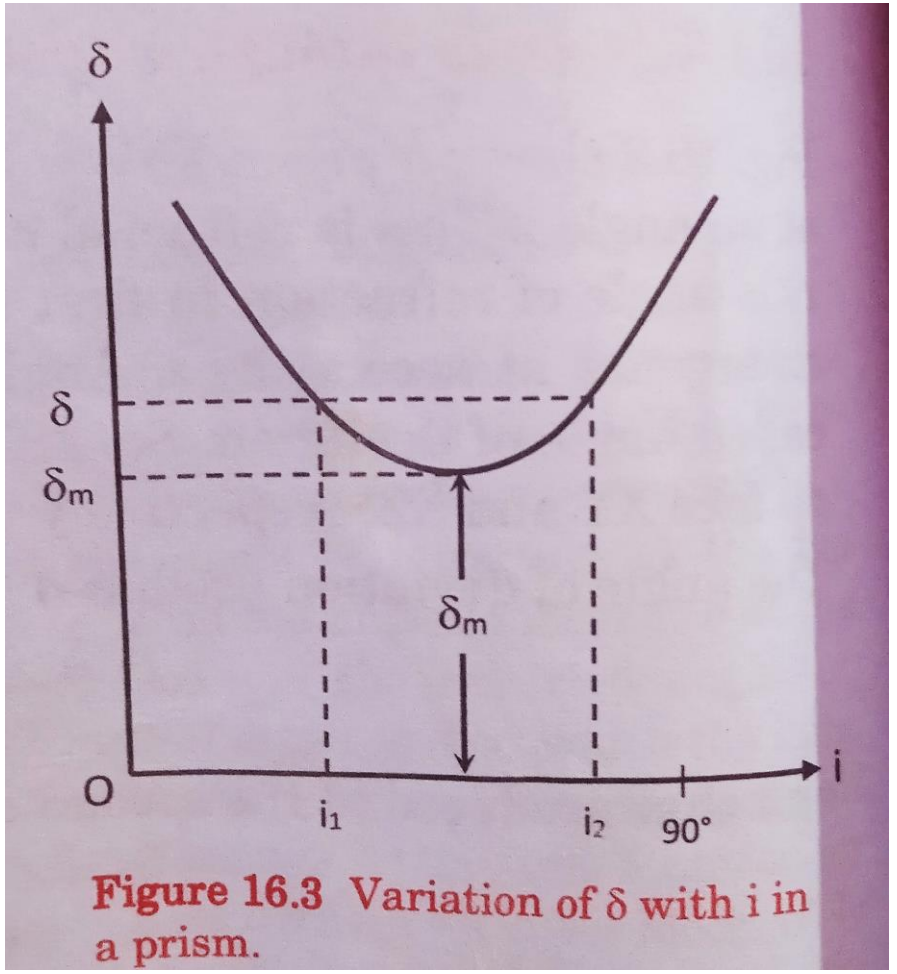


Figure 16.3 Variation of δ with i in a prism.

Now, using snell's law,

$$a\mu g = \frac{\sin i}{\sin r} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

We have,

$$\Rightarrow \delta + A = i + e$$

$$\Rightarrow \delta m + A = i + i$$

$$\Rightarrow i = \frac{A + \delta m}{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Also, we have,

$$\Rightarrow A = r_1 + r_2$$

$$\Rightarrow A = r + r$$

$$\Rightarrow A = 2r$$

$$\Rightarrow r = \frac{A}{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$\Rightarrow a\mu g = \frac{\sin(\frac{A+\delta m}{2})}{\sin\frac{A}{2}} \ldots\ldots\ldots\

Deviation of light from small angle prism:

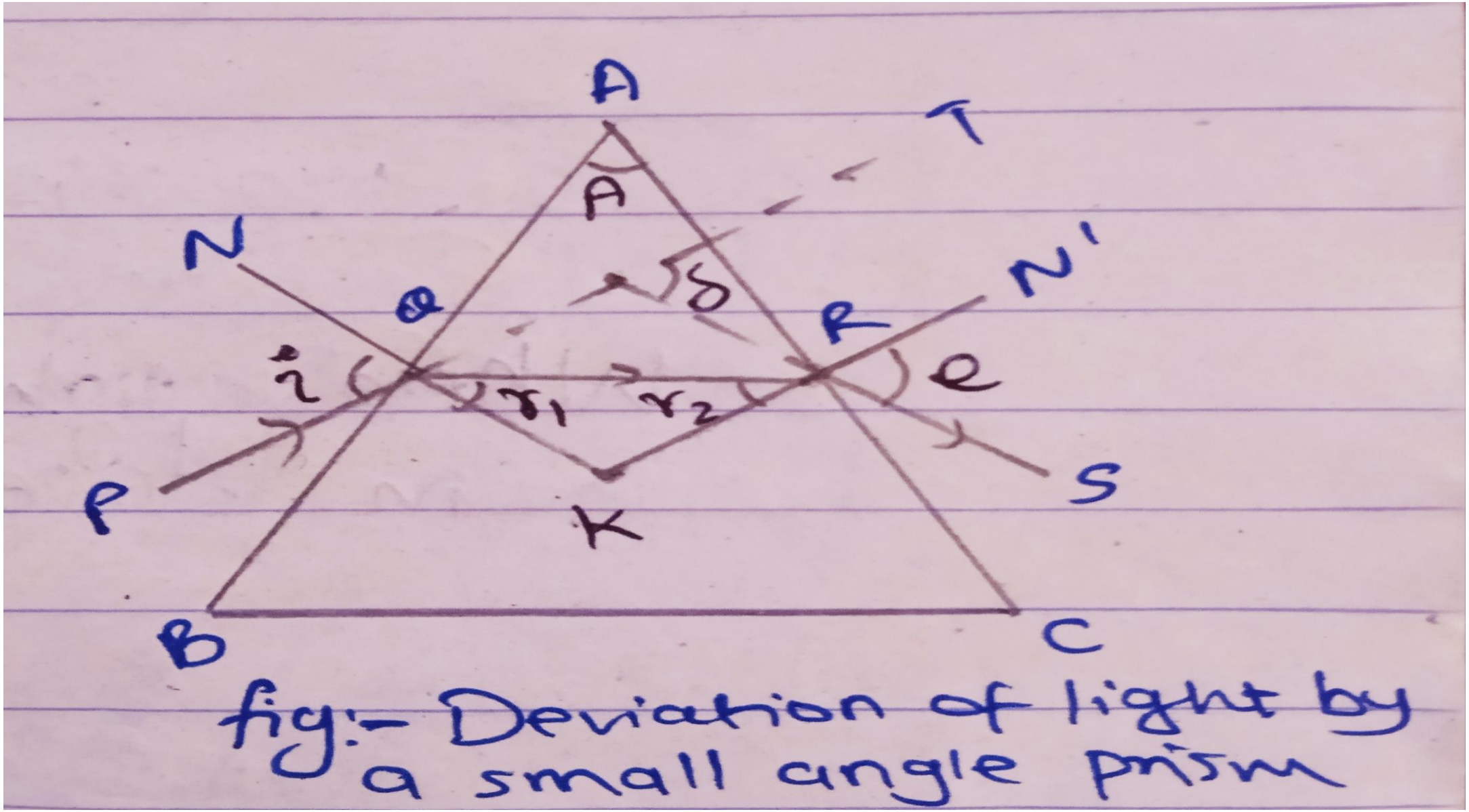


fig:- Deviation of light by a small angle prism

Above figure shows a prism ABC of small angle A about 10°-12°. When a ray of light PQ is incident on face AB with angle of incidence i, it is refracted along QR and finally emerges out along RS. Here, e is angle of emergence , r_1 is angle of refraction in the first face, r_2 is angle of incidence on the second face and δ is the angle of deviation. The angle of deviation of the ray PQ is given by

$$\Rightarrow \delta = i+e-A \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

When light ray travels from air to glass in the face AB, the refractive index is,

$$\Rightarrow a\mu g = \frac{\sin i}{\sin r_1}$$

from small angle prism, i and r_1 , are also very small. So, we can write,

$$\Rightarrow \sin i \approx i$$

$$\Rightarrow \sin r_1 \approx r_1$$

$$\Rightarrow a\mu g = \frac{i}{r_1}$$

$$\Rightarrow i = a\mu g\, r_1 \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

When light ray travels from glass to air in the face AC, the refractive index is,

$$\Rightarrow g\mu a = \frac{\sin r_2}{\sin e}$$

from small angle prism, e and r_2 , are also very small. So, we can write,

$$\Rightarrow \sin e \approx e$$

$$\Rightarrow \sin r_2 \approx r_2$$

$$\Rightarrow g\mu a = \frac{r_2}{e}$$

$$\Rightarrow \frac{1}{a\mu g} = \frac{r_2}{e}$$

$$\Rightarrow e = a\mu g\, r_2 \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Let,

$$\Rightarrow a\mu g = \mu$$

Equations (2) and(3) can be written as,

$$\Rightarrow i = \mu\, r_1 \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$\Rightarrow e = \mu\, r_2 \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

From equation (1),

$$\Rightarrow \delta = i + e - A$$

$$\Rightarrow \delta = \mu r_1 + \mu r_2 - A$$

$$\Rightarrow \delta = \mu (r_1 + r_2) - A$$

$$\Rightarrow \delta = \mu A - A$$

$$\Rightarrow \delta = A(\mu - 1)$$

The required expression shows that the angle of deviation is independent of the angle of incidence in a small angle prism.

Chapter 3 (SAQ)

Q.1 A glass prism is immersed in water. What happens to the value of angle of minimum deviation?

⇒When a glass prism is immersed in water,

$$\Rightarrow w\mu g = \frac{\sin\left(\frac{A+\delta m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

Since the value of relative refractive index $w\mu g$ is less than $a\mu g$ and hence, angle of minimum deviation also decreases being direct relationship.

Q.2 What are the factors on which the deviation produced by a thin prism depends?

⇒ The deviation produced by a thin prism is given by $\delta = A(\mu - 1)$. So, deviation produced depends upon the refractive index μ of the prism material and the angle of prism A.

Q.3 In the minimum deviation position, the ray through the prism is parallel to the base of the prism, why?

⇒ In the minimum deviation position, there is only one specific angle of incidence. This occurs when the angle of emergence is exactly equal to the angle of incidence. As a result, the ray passes symmetrically through the equilateral prism in this condition.

Q.4 Find the condition for no emergent of light from a prism.

⇒ For e=90°, then $r_2 = i_c$ therefore,

$$\Rightarrow r_1 + i_c = A$$

$$\Rightarrow r_1 = A - i_c$$

If $A > 2i_c$ we get the total internal reflection whatever is the value of incidence.

Grazing incidence and grazing emergence in a prism:

.

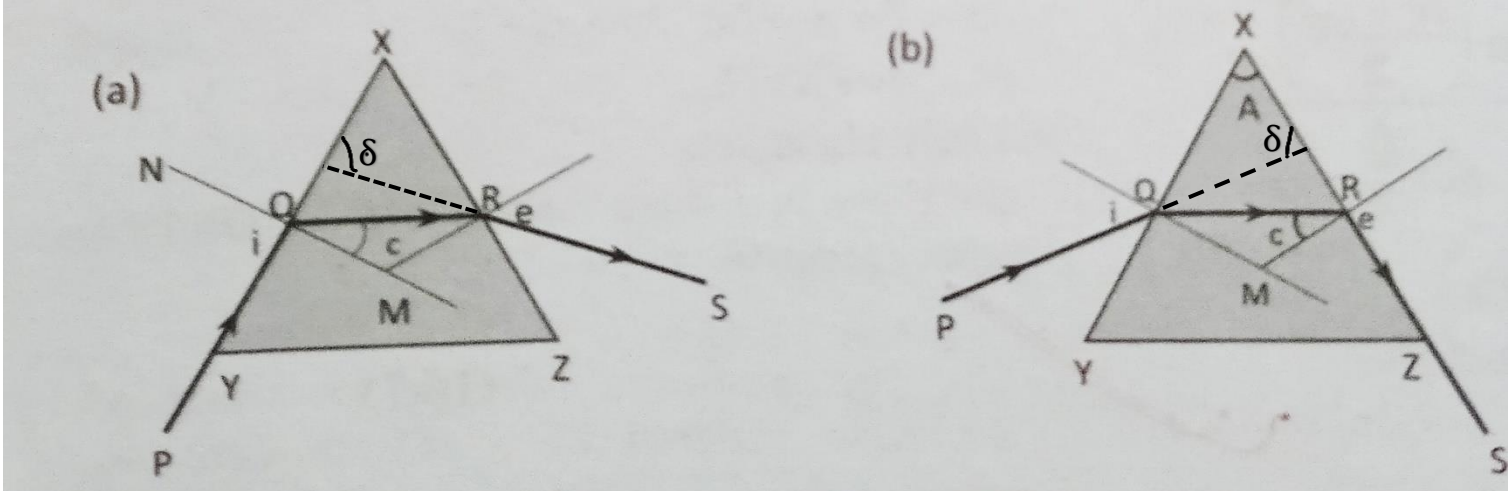


Figure 16.5 (a) Grazing incidence, (b) Grazing emergence

a) For the grazing incidence in the first face,

$$\Rightarrow \delta = i + e - A$$
$$\Rightarrow \delta = 90° + e - (r_1 + r_2)$$

$$\Rightarrow \delta = (90° - C) + (e - r_2)$$

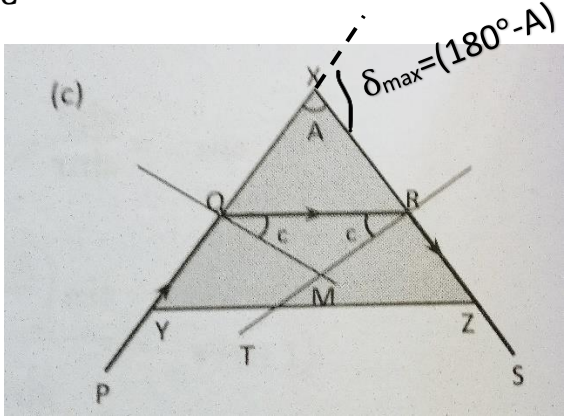
b) For the grazing emergence in the second face,

$$\Rightarrow \delta = i + e - A$$
$$\Rightarrow \delta = i + 90° - (r_1 + r_2)$$

$$\Rightarrow \delta = (90° - C) + (i - r_1)$$

c) For the simultaneous grazing incidence and grazing emergence in a prism,

$$\Rightarrow \delta max = i + e - A$$
$$\Rightarrow \delta max = 90° + 90° - (C + C)$$
$$\Rightarrow \delta max = 180° - 2C$$



Limiting angle: The largest angle of prism for which grazing incidence and grazing emergence can occur simultaneously is called limiting angle of prism. For this,

$$\Rightarrow A=C+C$$

$$\Rightarrow A=2C$$

Chapter :4 Lenses

Lens: A lens is a transparent refracting medium bounded by two spherical surfaces. It is divided into two classes. They are:

1. Convex lens (or converging lens)
2. Concave lens (or diverging lens)

Convex Lens: A lens whose middle part is thicker than its edge is called convex lens. In convex lens, a parallel beam of light comes to meet at focus after refraction through the lens. Convex lens is divided into three types:

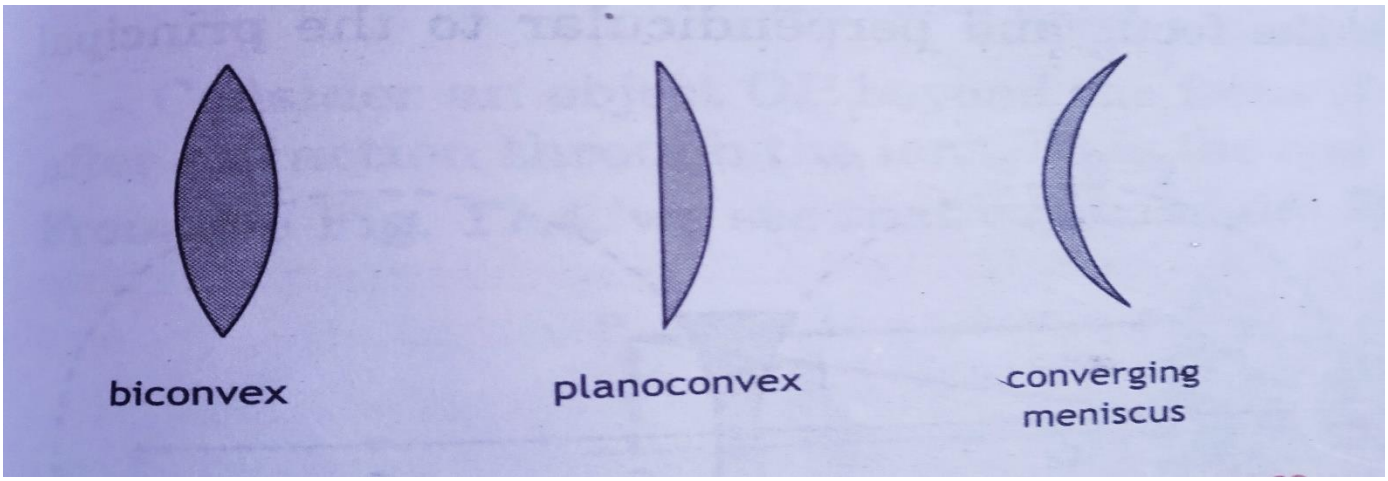
1. Bi-convex lens: In this lens, both surfaces are convex. If both surfaces of a biconvex lens are identical, the lens is called equiconvex lens.

$$\text{i.e. } R_1=R_2$$

2. Plano-convex lens: In this lens, one surface is plane and another surface is convex.

3. Concave-convex lens (converging meniscus): In this lens, one surface is concave and another surface is convex such that the radius of curvature of convex surface is smaller than that of concave surface.

$$\text{i.e. } R_{convex}<R_{concave}$$



Concave Lens: A lens which is thinner in middle than its edge is called concave lens. In concave lens, a parallel beam of light diverges after refraction through the lens. Concave lens is further divided into three types:

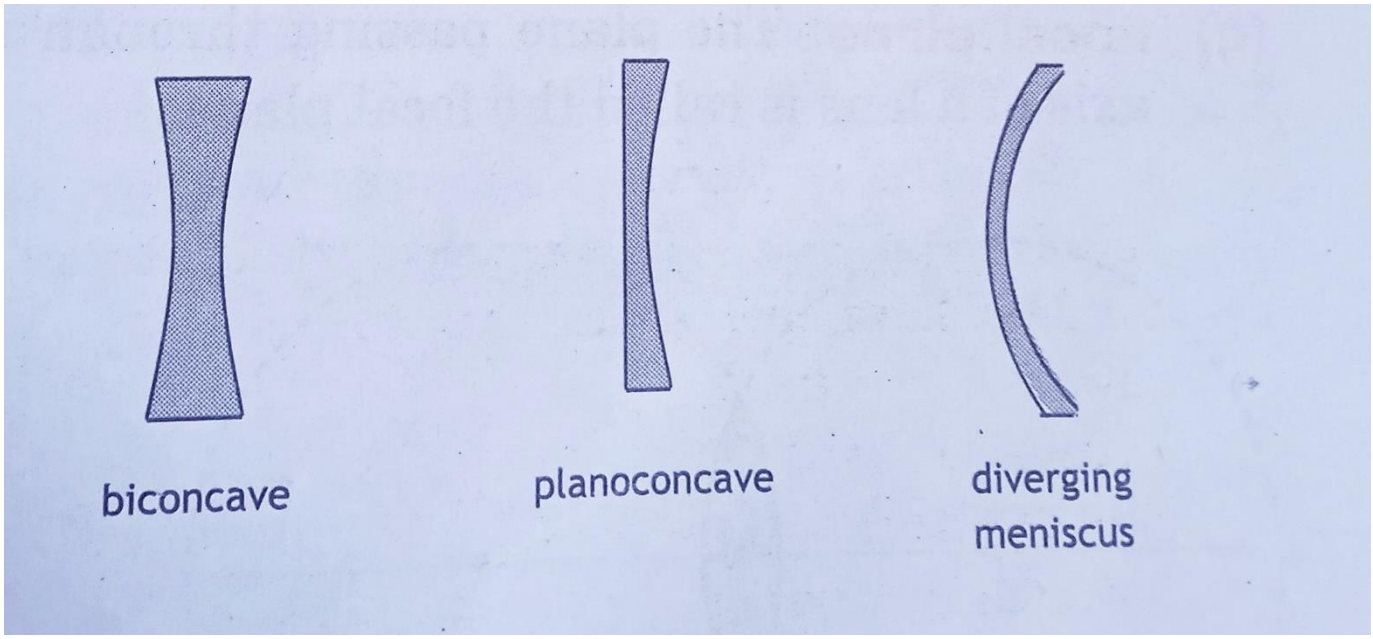
1. Bi-concave lens: In this lens, both surfaces are concave. If both surfaces of a biconcave lens are identical, the lens is called equi-concave lens.

i.e. $R_1=R_2$

2. Plano-concave lens: In this lens, one surface is plane and another surface is concave.

3. Convex-concave lens (diverging meniscus): In this lens, one surface is concave and another surface is convex such that the radius of curvature of concave surface is smaller than that of convex surface.

i.e. $R_{concave}<R_{convex}$



Lens Formula: The relation between object distance, image distance and focal length of lens is called lens formula. It is expressed as,

$$\Rightarrow \frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

Where, f =focal length

u= object distance

v= image distance

Lens Formula for convex lens when real image is formed:

Let an object AB be placed in front of a thin convex lens of focal length 'f' so that its image A'B' is formed on the another side of lens as shown in figure.

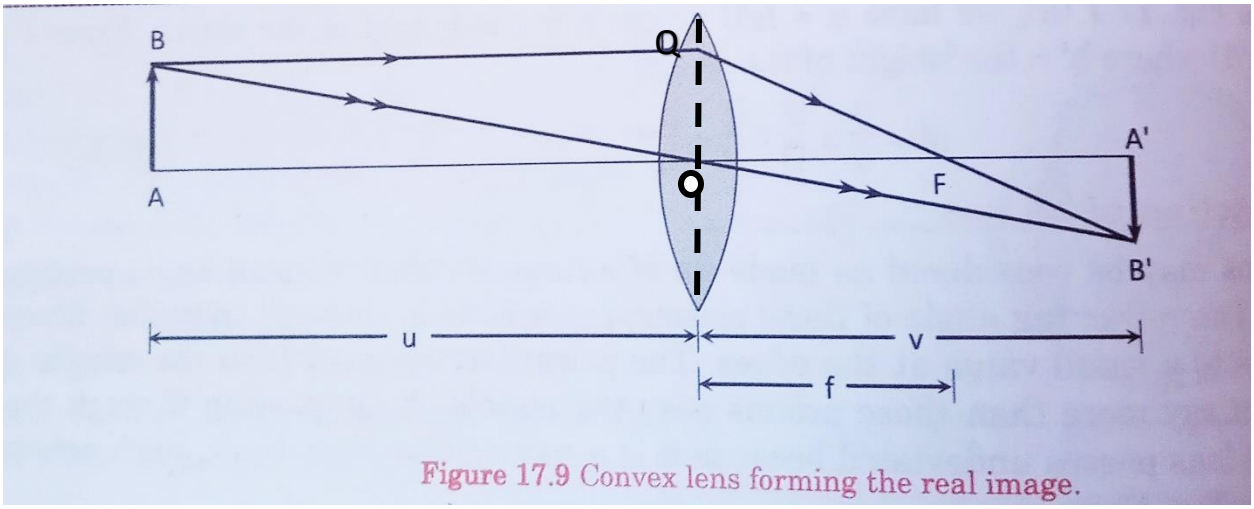


Figure 17.9 Convex lens forming the real image.

In the figure,

OF= f= focal length

OA=u= object distance

OA'= v= image distance

And, AB= OQ

From the figure, it is clearly seen that ΔABO and ΔA'B'O are similar. So, we have

$$\Rightarrow \frac{AB}{A'B'} = \frac{OA}{OA'} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Also, ΔA'B'F and ΔOQF are similar. So we have,

$$\Rightarrow \frac{OQ}{A'B'} = \frac{OF}{A'F} \text{.....(2)}$$

$$\Rightarrow \frac{AB}{A'B'} = \frac{OF}{A'F} \text{.....(3) (since AB=OQ)}$$

Now, from equation (1) and (3) , we get

$$\Rightarrow \frac{OA}{OA'} = \frac{OF}{A'F}$$

$$\Rightarrow \frac{u}{v} = \frac{f}{OA' - OF}$$

$$\Rightarrow \frac{u}{v} = \frac{f}{v - f}$$

$$\Rightarrow u(v - f) = vf$$

$$\Rightarrow uv - uf = vf$$

$$\Rightarrow uv = uf + vf$$

Dividing both sides by uvf, we get,

$$\Rightarrow \frac{uv}{uvf} = \frac{uf}{uvf} + \frac{vf}{uvf}$$

$$\Rightarrow \frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

This is the required expression for lens formula.

Lens maker's formula: The relation between the focal length of lens, radii of curvature of two surfaces and refractive index of the material is called lens maker's formula. It is expressed as,

$$\Rightarrow \frac{1}{f} = (\mu - 1)(\frac{1}{R_1} + \frac{1}{R_2})$$

Where, f= focal length of lens

μ= refractive index of material of lens

R_1= radius of curvature of first surface

R_2 = radius of curvature of second surface

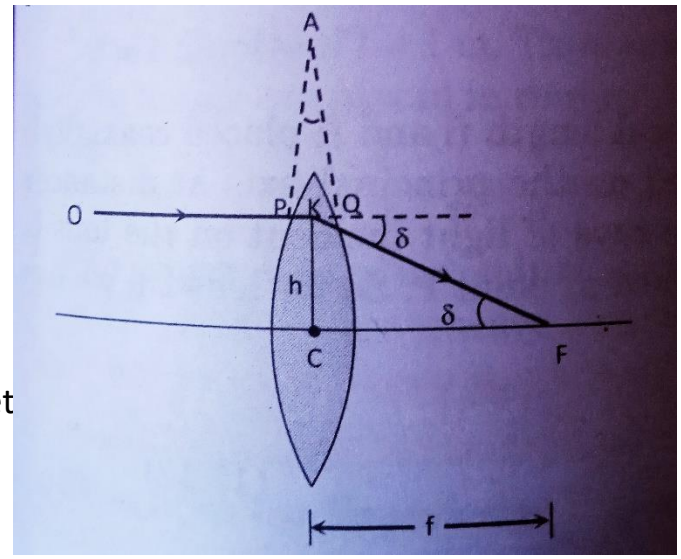


Figure: Refraction through lens

Consider a thin convex lens of focal length 'f'. Let a ray of light OP parallel to the principle axis is incident at the point 'K' at height 'h' above the optical center 'C' as shown in the figure. This ray after refraction through lens meets at focus 'F' making angle of deviation 'δ' on drawing tangents at the light deviating points of the lens, a small angled prism of 'A' is formed.

Now, in ΔKCF,

$$\Rightarrow tan\delta = \frac{KC}{CF}$$

$$\Rightarrow tan\delta = \frac{h}{f}$$

Since, the lens is thin, the angle δ is very small, so

$$\Rightarrow tan\delta \approx \delta$$

$$\Rightarrow \delta = \frac{h}{f} \quad \text{.....(1)}$$

And, the deviation through a small angle prism is given by,

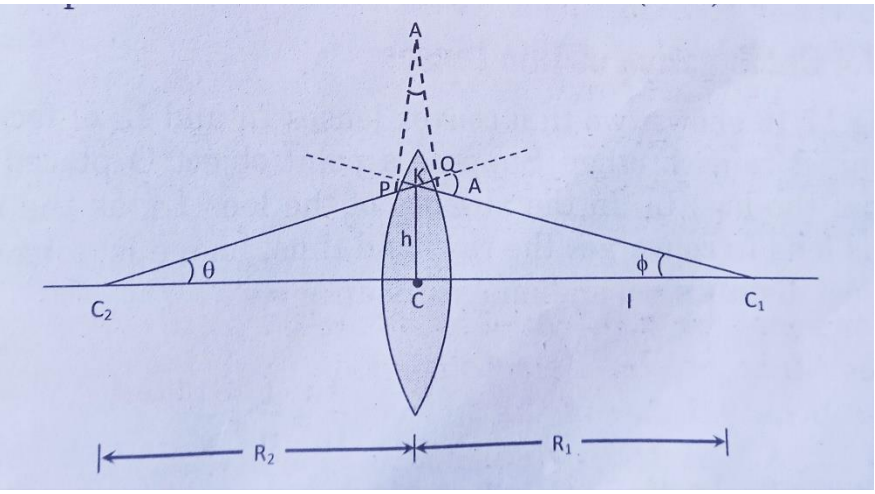
$$\Rightarrow \delta = A(\mu - 1) \text{ .....(2)}$$

From equation (1) and (2) ,we get

$$\Rightarrow A(\mu - 1) = \frac{h}{f}$$

$$\Rightarrow \frac{A}{h}(\mu - 1) = \frac{1}{f} \text{.....(3)}$$

To find A/h, we construct a figure as shown in figure below. Let CC_1 and CC_2 be radii of curvature of the lens and θ and Φ are the angles made by the normals AC_1 and PC_2 with the principle axis respectively.



Since, the angle between tangents is equal to the angle between their normals.

$$\Rightarrow \angle \mathrm{PKC_2} = \angle \mathrm{QKC_1} = \mathrm{A}$$

From the geometry of the figure,

$$\Rightarrow \mathrm{A} = \theta + \Phi \text{ .....(4)}$$

Also $\Rightarrow tan\theta = \frac{\mathrm{h}}{\mathrm{R_1}}$ and $\Rightarrow tan\Phi = \frac{\mathrm{h}}{\mathrm{R_2}}$

But θ and Φ are very small, so we can write above relation as,

$\Rightarrow \theta = \frac{h}{R_1}$ and $\Rightarrow \Phi = \frac{h}{R_2}$.....(5)

Now using equation (4) and (5) , we get

$$\Rightarrow A = \frac{h}{R_1} + \frac{h}{R_2}$$

$$\Rightarrow A = h(\frac{1}{R_1} + \frac{1}{R_2})$$

$$\Rightarrow \frac{A}{h} = (\frac{1}{R_1} + \frac{1}{R_2}) \text{ .....(6)}$$

From equation (3) and (6), we get

$$\Rightarrow \frac{1}{f} = (\mu - 1)(\frac{1}{R_1} + \frac{1}{R_2})$$

This is the required expression for lens maker's formula.

Power of Lens: Power of lens is a measure of its ability to produce deviation of light. The reciprocal of focal length is called power of lens.

$$.Power\ of\ lens(P) = \frac{1}{focal\ length}$$

The SI unit of power of lens is m^{-1} which is called the Dioptre (D).

Visual angle: The angle subtended by an object at the eye is defined as the visual angle.

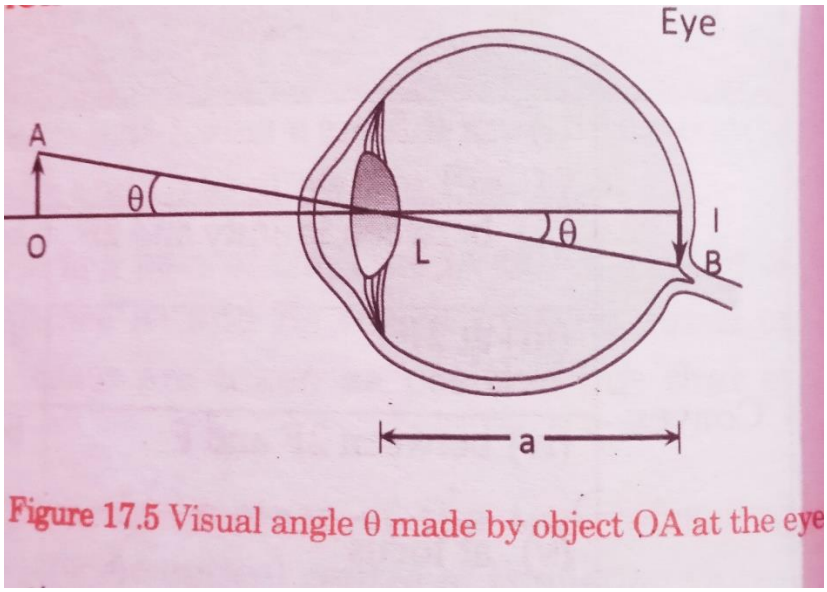


Figure 17.5 Visual angle θ made by object OA at the eye

Suppose an object OA is placed in front of eye, θ is the visual angle due to object OA, IB = y is the size of image formed at the retina of eye. 'a' is the distance between the eye lens and retina.

The size of image formed is given as

$$\Rightarrow \theta = \frac{y}{a}$$

$$\Rightarrow \ y = a\theta$$

Here, 'a' is constant.

$$\Rightarrow \; y \propto \theta$$

Thus, the size of image formed by the eye is proportional to the visual angle.

Angular magnification: Angular magnification is the ratio of the visual angle subtended by the image formed by an optical instrument at the eye, to the visual angle subtended by the object when kept at the least distance of distinct vision (D) (normally 25cm) and viewed directly by the unaided eye. Let α be the angle subtended at the unaided eye by the object at the near point and β be the angle subtended at the lens by the image at the same distance.

$$angular\ magnification\ (M) = \frac{\beta}{\alpha}$$

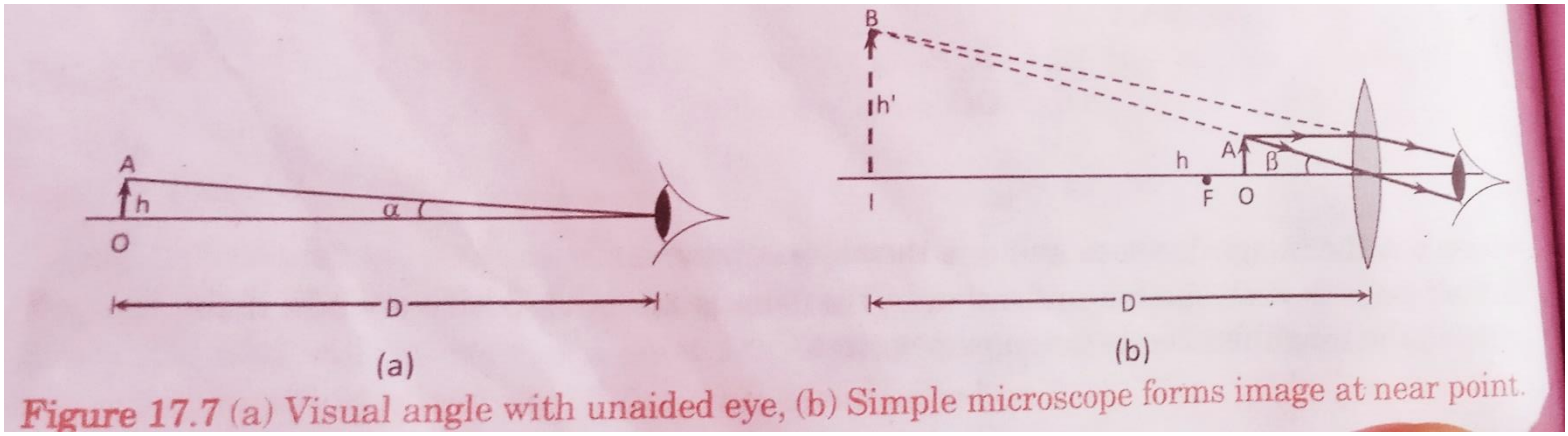


Figure 17.7 (a) Visual angle with unaided eye, (b) Simple microscope forms image at near point.

Combined focal length of two thin lenses in contact:

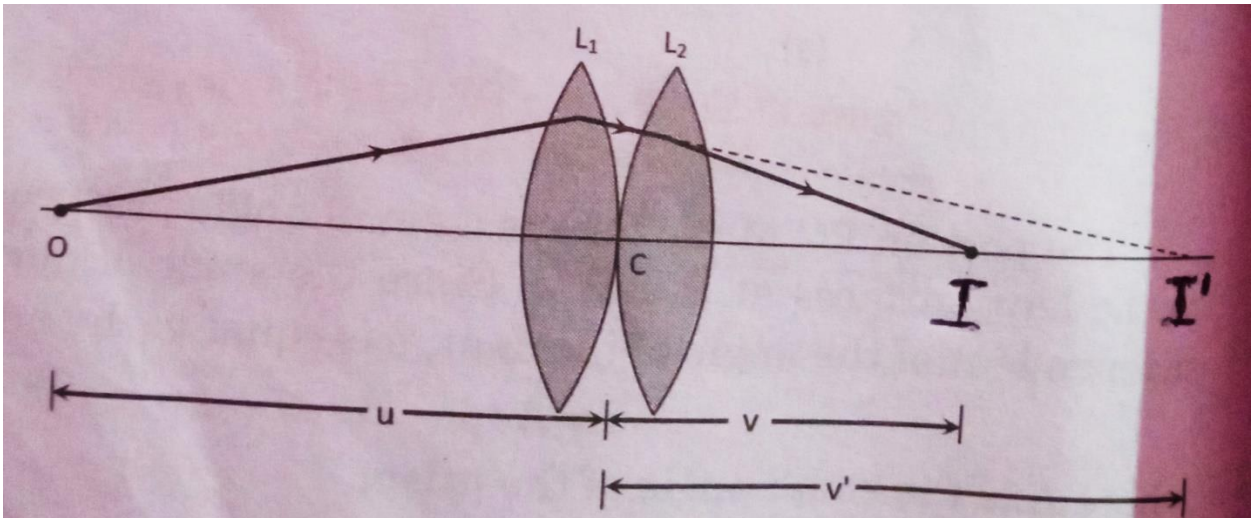


Figure 17.12 Combined focal length of two thin lenses.

Let us consider two lenses L_1 and L_2 of focal length f_1 and f_2 placed co-axially in contact with each other as shown in figure. Suppose a point object 'O' placed on the principal axis at distance 'u' from the lens L_1. In the absence of the lens L_2, as the rays of light incident on the lens L_1, this lens L_1 converges the rays and thus, image is formed at point I'. So far lens L_1, we have object distance=u and image distance=v'.

$$\Rightarrow \frac{1}{f_1} = \frac{1}{u} + \frac{1}{v'} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

When lens L_2 is placed in contact, the image at I' acts as virtual object for lens L_2, since the converging beam is incident on L_2, . for L_2,

Object distance = -v'

Image distance= v

$$\Rightarrow \quad \frac{1}{f_2} = \frac{1}{-v'} + \frac{1}{v} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Adding equation (1) and (2), we get

$$\Rightarrow \frac{1}{f_1}+\frac{1}{f_2}=\frac{1}{u}+\frac{1}{v'}-\frac{1}{v'}+\frac{1}{v}$$

$$\Rightarrow \frac{1}{f_1}+\frac{1}{f_2}=\frac{1}{u}+\frac{1}{v}\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

IF F is the combined focal length of two thin lenses placed in contact having object distance u and image distance v , then

$$\Rightarrow \frac{1}{F}=\frac{1}{u}+\frac{1}{v}\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

From equation (3) and (4) ,

$$\Rightarrow \frac{1}{f_1}+\frac{1}{f_2}=\frac{1}{F}$$

Here, F is called equivalent focal length of two thin lenses in contact.

SAQ

Q.1 A large object when taken away from your eye appears smaller, why?

⇒ We know that , the size of image formed at the retina of eye is proportional to the angle subtended by the object at the eye. When a large object is taken away from our eye, the angle made by the object at the eye i.e. visual angle decreases and the image of the object at the retina of eye appears smaller.

Q.2 The surfaces of sun glasses are curved but power is zero, how ?

⇒ In the sun glasses, both of surfaces are curved to the same side i.e. their center of curvatures are same. So, their radius of curvature are equal but opposite in sign, R_1 =R and R_2 =-R . The focal length of lens is given by,

$$\Rightarrow\frac{1}{f}=(\mu-1)(\frac{1}{R_1}+\frac{1}{R_2})$$

$$\Rightarrow\frac{1}{f}=(\mu-1)(\frac{1}{R}-\frac{1}{R})$$

$$\Rightarrow power(P) = \frac{1}{f} = 0$$

Q.3 An air bubble is formed inside the water. Does it act as a converging lens or diverging lens?

⇒ The focal length of lens according to lens maker's formula is

$$\frac{1}{f} = (\mu - 1)(\frac{1}{R_1} + \frac{1}{R_2})$$

Here, the air bubble acts as the lens. Since μ is the refractive index of air (i.e. lens) relative to the water, μ<1 which makes (μ-1) negative so that the focal length (f) becomes negative. This means light ray diverges through the air bubble. Thus, the bubble acts as a diverging lens.

Q.4 A lens is made of glass is immersed with water. Will its power increase, or decrease?

⇒ The power of lens in air is given by,

$$P_1 = \frac{1}{f_1} = (a\mu_g - 1)(\frac{1}{R_1} + \frac{1}{R_2})$$

Where, ${}_a\mu_g$ is refractive index of glass lens relative to air, R_1 and R_2 are radii of curvature of two surfaces of lens. Similarly, the power of the lens when it is immersed in water is given by,

$$P_2 = \frac{1}{f_2} = (w\mu_g - 1)(\frac{1}{R_1} + \frac{1}{R_2})$$

Where, ${}_w\mu_g$ is refractive index of glass lens relative to water,. Here, ${}_w\mu_g = \frac{a\mu_g}{a\mu_w}$ is less than ${}_a\mu_g$..So, the factor (${}_w\mu_g$-1) is less than (${}_a\mu_g$-1). Therefore $P_2 < P_1$ which means the power of lens decrease when it is immersed in water.

Chapter-18 Dispersion

Dispersion: The phenomenon of splitting of white light into its constituent colours is called dispersion of light.

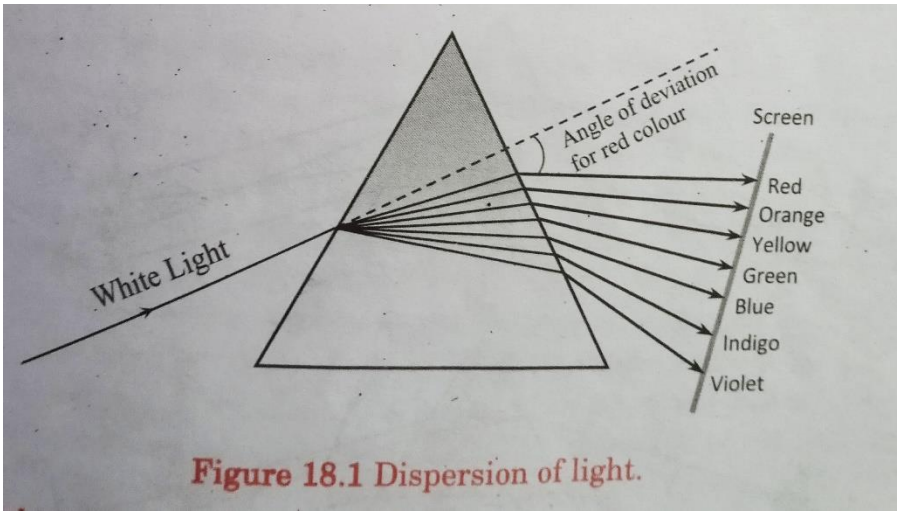


Figure 18.1 Dispersion of light.

Cauchy Relation: The relationship between refractive index and wavelength of different colour of lights in dispersion is called Cauchy relation. Mathematically,

$$\mu = a + \frac{b}{\lambda^2} + \frac{c}{\lambda^4}$$

Where a, b and c are the constants for the material of prism.

Impure and Pure Spectrum: If the split rays overlap to each other, all colours can not be seen distinctly on the screen. Such spectrum is called the impure spectrum. However, if the spectrum on the screen in which the split colours do not overlap to each other, all colours can be seen distinctly and this is called the pure spectrum.

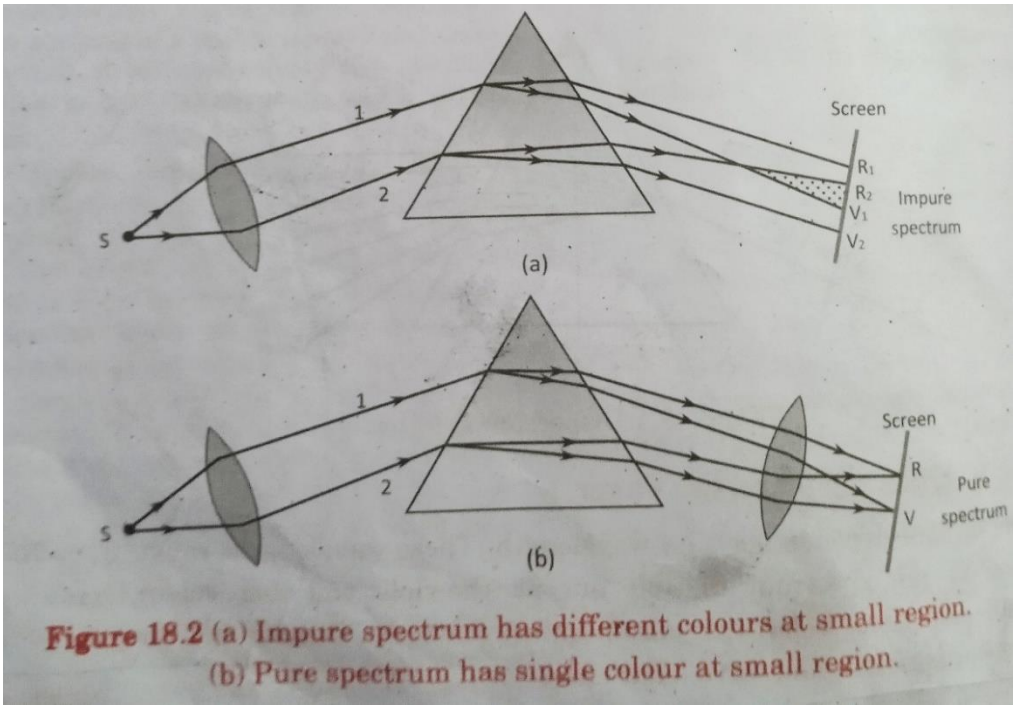


Figure 18.2 (a) Impure spectrum has different colours at small region. (b) Pure spectrum has single colour at small region.

Angular Dispersion: The angular dispersion is defined as the differences between angle of deviation of two extreme colours of light (i.e. violet and red).

$$\text{Angular dispersion} = \delta_v - \delta_R \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Since the deviation in small angle prism is

$\delta = A(\mu - 1)$, then

deviation for violet light, $\delta_v = A(\mu_v - 1)$,

and

deviation of red light, $\delta_R = A(\mu_R - 1)$,

Where, A is the angle of prism.

Substituting the value of δv and δ_R in equation (1) , we get

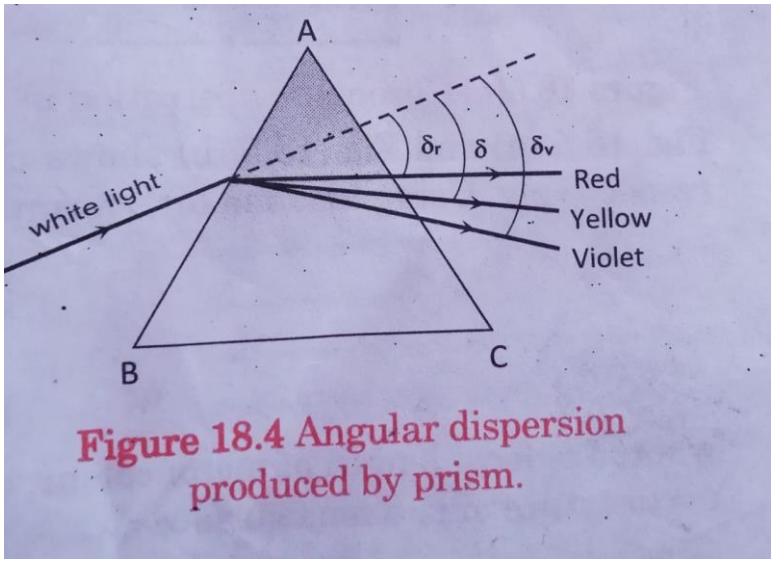


Figure 18.4 Angular dispersion produced by prism.

$$\text{Angular dispersion} = \delta_v - \delta_R = A(\mu_v - 1) - A(\mu_R - 1)$$

$$\Rightarrow \text{Angular dispersion} = A(\mu_v - \mu_R)$$

Dispersive power: It is the ratio of angular dispersion to the deviation of mean colour.

⇒Dispersive power (w) $=\frac{\delta v-\delta R}{\delta}$

The angle of deviation for mean colour $\delta=A(\mu\text{-}1)$, then

⇒Dispersive power (w) $=\frac{A(\mu_V-1)-A(\mu_R-1)}{A(\mu-1)}=\frac{\mu_V-\mu_R}{\mu-1}$

Chromatic aberration: The inability of lens to focus all colours of light at a single point is called the chromatic aberration or axial or longitudinal chromatic aberration.

⇒ Chromatic aberration=f_R-f_v

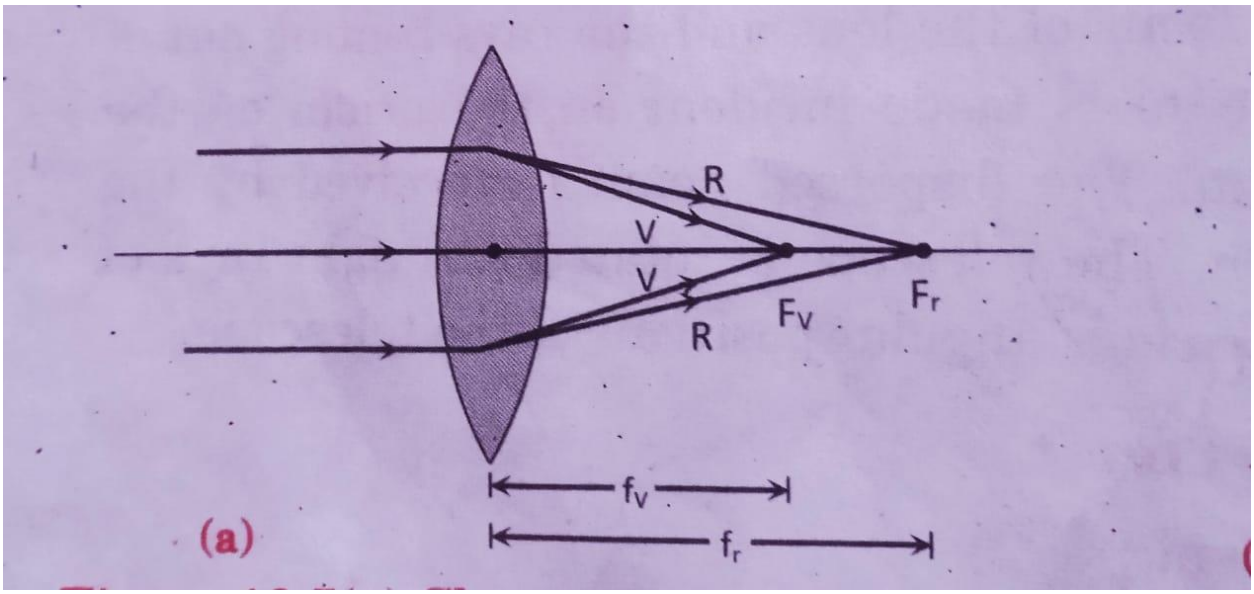


Figure : Chromatic aberration in a convex lens.

Using lens maker's formula, for mean colour of light, we have

$$\Rightarrow \frac{1}{f}=(\mu-1)(\frac{1}{R_1}+\frac{1}{R_2})$$

$$\Rightarrow \frac{1}{f(\mu-1)}=(\frac{1}{R_1}+\frac{1}{R_2})$$

Where, f is the focal length of mean colour, μ is refractive index of mean colour, R_1 and R_2 are radii of curvature of two lens surfaces.

For violet light, we have

$$\Rightarrow \frac{1}{f_v} = (\mu_v - 1)(\frac{1}{R_1} + \frac{1}{R_2})$$

$$\Rightarrow \frac{1}{f_v} = (\mu_v - 1)\frac{1}{f(\mu - 1)}$$

……(1)

Similarly, for red light, we have

$$\Rightarrow \frac{1}{f_R} = (\mu_R - 1)\frac{1}{f(\mu - 1)}$$

……(2)

Subtracting equation (2) from equation (1), we get

$$\Rightarrow \frac{1}{f_v} - \frac{1}{f_R} = (\mu_v - 1)\frac{1}{f(\mu - 1)} - (\mu_R - 1)\frac{1}{f(\mu - 1)}$$

$$\Rightarrow \frac{f_R - f_v}{f_v f_R} = (\mu_v - 1)\frac{1}{f(\mu - 1)} - (\mu_R - 1)\frac{1}{f(\mu - 1)}$$

$$\Rightarrow f_R - f_v = \frac{(\mu_v - 1 - \mu_R + 1)f_v f_R}{f(\mu - 1)}$$

$$\Rightarrow f_R - f_v = \frac{(\mu_v - \mu_R)f_v f_R}{f(\mu - 1)}$$

Since focal lengths of seven colours are in geometric progression, so we can write

$$\Rightarrow f = \sqrt{(f_v f_R)}$$

$$\Rightarrow f^2 = f_v f_R$$

$$\Rightarrow f_R - f_v = \frac{(\mu_v - \mu_R)f^2}{f(\mu - 1)}$$

$$\Rightarrow f_R - f_v = wf$$

Achromatic combination of lenses:

The combination of two thin lenses in which it is free from chromatic aberration is called the achromatic combination of lenses.

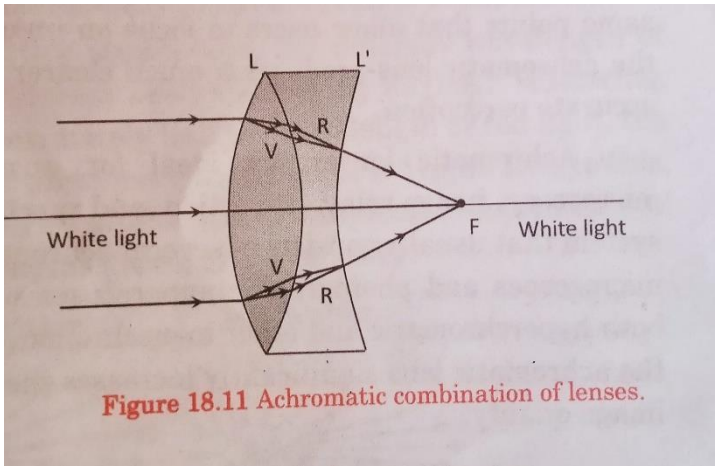


Figure 18.11 Achromatic combination of lenses.

Consider two thin lenses L and L' of dispersive Power w and w' respectively placed in contact With each other as shown in figure.

Let μ_v, μ and μ_R are the refractive indices of L for violet, mean, and red colour respectively, and f_v , f, f_R are focal lengths of the respective colours. Similarly, μ'_v, μ' and μ'_R ; f'_v , f', f'_R are corresponding quantities of L'.

focal length of lens L for mean colour is

$$\Rightarrow \frac{1}{f} = (\mu - 1)(\frac{1}{R_1} + \frac{1}{R_2})$$

$$\Rightarrow \frac{1}{f(\mu - 1)} = (\frac{1}{R_1} + \frac{1}{R_2})$$

Focal length of lens L for violet colour is

$$\Rightarrow \frac{1}{f_v} = (\mu_v - 1)(\frac{1}{R_1} + \frac{1}{R_2})$$

$$\Rightarrow \frac{1}{f_v} = (\mu_v - 1)\frac{1}{f(\mu - 1)}$$

Similarly, focal length of lens L' for violet colour

$$\Rightarrow \frac{1}{f'_v} = (\mu'_v - 1)\frac{1}{f'(\mu' - 1)}$$

If F_v is the combined focal length of two lenses for violet colour, then

$$\Rightarrow \frac{1}{F_V} = \frac{1}{f_v} + \frac{1}{f'_v}$$

$$\Rightarrow \frac{1}{F_V} = (\mu_v - 1)\frac{1}{f(\mu-1)} + (\mu'_v - 1)\frac{1}{f'(\mu'-1)}$$

In the same way for red colour of light

$$\Rightarrow \frac{1}{F_R} = (\mu_R - 1)\frac{1}{f(\mu-1)} + (\mu'_R - 1)\frac{1}{f'(\mu'-1)}$$

For achromatic combination, we have

$$\Rightarrow F_R = F_V$$

$$\Rightarrow \frac{1}{F_R} = \frac{1}{F_v}$$

$$\Rightarrow \frac{(\mu_R - 1)}{f(\mu - 1)} + \frac{(\mu'_R - 1)}{f'(\mu' - 1)} = \frac{(\mu_v - 1)}{f(\mu - 1)} + \frac{(\mu'_v - 1)}{f'(\mu' - 1)}$$

$$\Rightarrow \frac{(\mu'_R - 1)}{f'(\mu' - 1)} - \frac{(\mu'_v - 1)}{f'(\mu' - 1)} = \frac{(\mu_v - 1)}{f(\mu - 1)} - \frac{(\mu_R - 1)}{f(\mu - 1)}$$

$$\Rightarrow -\frac{(\mu'_v - \mu'_R)}{f'(\mu' - 1)} = \frac{(\mu_v - \mu_R)}{f(\mu - 1)}$$

$$\Rightarrow -\frac{w'}{f'} = \frac{w}{f}$$

$$\Rightarrow \frac{w}{f} + \frac{w'}{f'} = 0$$

This is the condition for achromatic combination of two lenses.

Spherical Aberration in a Lens:

When a point object O is placed on the principal axis of a large lens, paraxial rays and marginal rays form images at different points (IP and IM) on the axis. Paraxial rays focus farther from the lens than marginal rays, so a sharp image is not formed at any single point. If a screen is placed perpendicular to the axis, the image appears as a circular patch instead of a point. This patch is called the circle of least confusion, and its radius gives the measure of lateral spherical aberration. When the aperture of a lens is large compared to its focal length, rays passing through different zones of the lens do not converge at the same point. As a result, the image of a point object spreads between IM and IP along the axis. This defect is known as spherical aberration.

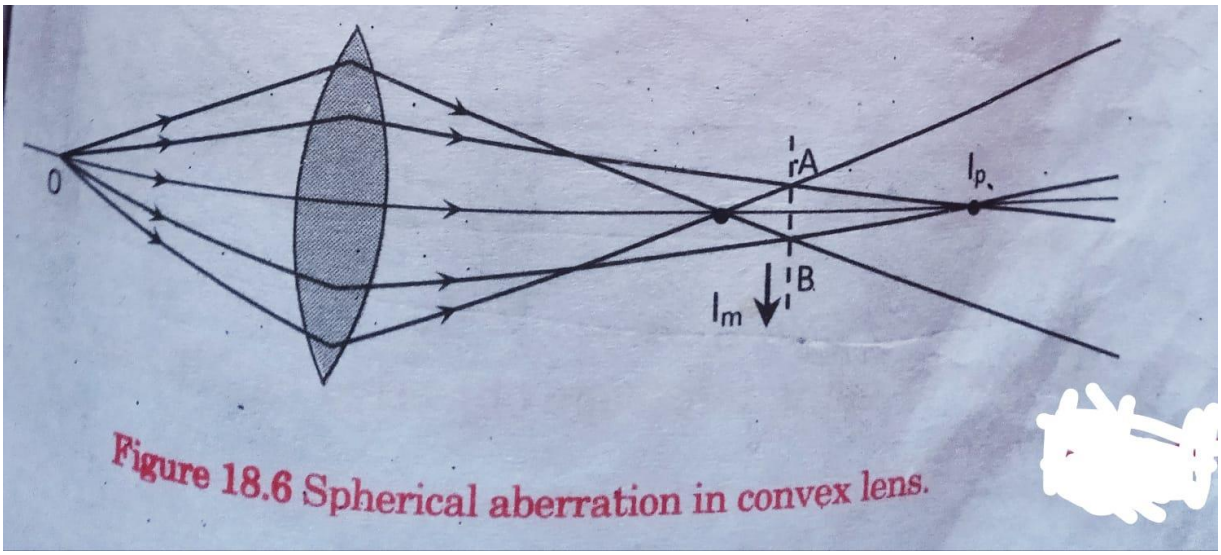


Figure 18.6 Spherical aberration in convex lens.

Removal of Spherical Aberration in a Lenses:

1. By using stop: Spherical aberration can be reduced either by cutting off the paraxial rays or by cutting off the marginal rays.

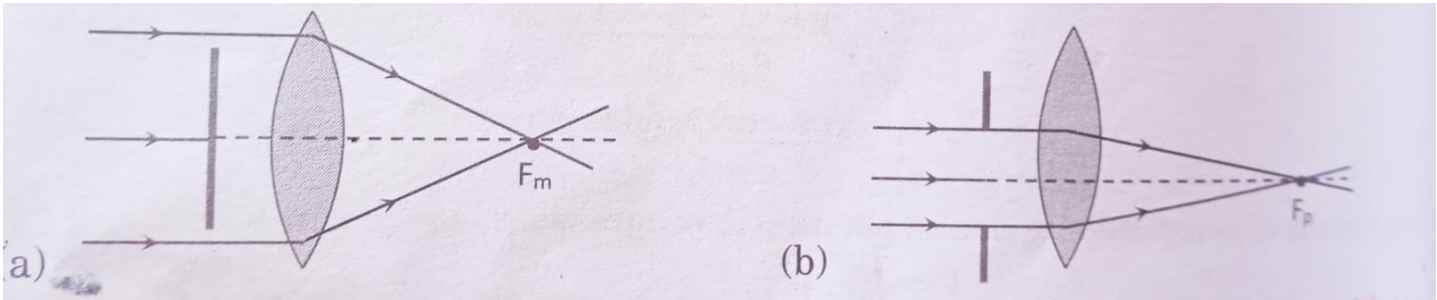


Figure 18.8 Reduction of spherical aberration by using stops in different positions

2. By combining suitable concave and convex lenses: It is known that convex lens has positive spherical aberration and concave lens has negative spherical aberration. So, by selecting suitable pair of convex and concave lens, spherical aberration can be minimized.

Rayleigh law of scattering:

The intensity of light scattered from fine particles (dimension $\leq$ wavelength of light) is inversely proportional to the fourth power of wavelength of light.

i.e.

$$I \propto \frac{1}{\lambda^4}$$

Blue colour of sky: When sunlight passes through the earth's atmosphere, it get scattered by very small particles (gaseous molecule) of the atmosphere. According to Rayleigh law of scattering, the intensity of light scattered from fine particles is inversely proportional to the fourth power of wavelength of light. The wavelength of blue colour of light is smaller than the red colour, therefore, blue light is scattered more than the red light. So, the blue light dominates and sky appears blue when the sun is well above in the sky.

SAQ

Q.1) Explain, why an achromatic doublet can not be made of the same material?

We, know the condition for achromatic doublet,

$$\Rightarrow \frac{w}{f} + \frac{w'}{f'} = 0$$

If w=w' then f=-f'. So, total power P=o and behave as a glass plate.

Q.2) When white light is dispersed by a prism, red light appears at the top of the spectrum whereas violet at the bottom, why?

The angle of deviation depends on refractive index of prism. As the refractive index depends on the wavelength of light and $\mu_v > \mu_r$,the violet light deviates more and red least in the prism.

Q.3) How does the angle of minimum deviation of a glass prism vary, if the incident violet light is replaced with red light?

The deviation produced by a small angle prism is given by $\delta = A(\mu-1)$. As, $\mu_v > \mu_r$ so $\delta v > \delta r$, hence the angle of minimum deviation decreases when red light is used.

Q.4) A thick lens suffers from chromatic aberration while a thin lens does not do so, why?

A lens behaves as combination of prisms. Thick lens has angle of prism quite larger in comparison to that in case of a thin lens. Since, the angular dispersion produced by a prism is directly proportional to the angle of prism, a thick lens suffers chromatic aberration, while for a thin lens the chromatic aberration may be zero.

Q.5) Why there is no dispersion of monochromatic light?

When monochromatic light is incident on the prism, it can not be split due to having single wavelength. So, there is no dispersion of monochromatic light.

Q.6) Why is yellow sodium light is used for illumination in foggy conditions/

Yellow light has longer wavelength than blue , green or violet components of white light. As scattered intensity $\propto 1/\lambda^4$, so yellow colour is least scattered and produces sufficient illumination. That is why yellow sodium light is used for illumination in foggy conditions.